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Twenty Years Growth of a Sprout Hardwood Forest in New York: A Study of the Effects of Intermediate and Reproduction Cuttings

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TWENTY YEARS GROWTH OF A SPROUT HARDWOOD FOREST IN NEW YORK:

A STUDY OF THE EFFECTS OF INTERMEDIATE AND REPRODUCTION CUTTINGS

J. Nelson Spaeth

The information here presented was obtained by the author in a recent study of sample plots on which silvicultural cuttings were made twenty years ago. It comprises growth data showing quantitatively the results of silvicultural treatment in a sprout hardwood forest in which three distinctly different tree associations, or forest types, were recognized. For each of these types, results of twenty years growth are shown in rate of diameter increase of the principal species, volume growth per acre in cubic feet, board feet, and cords, volume growth of the entire forest by compartments, and amount and character of the reproduction resulting from the cuttings.

DESCRIPTION OF THE FOREST

LOCATION

The study was made in the woodland of Crumwold Farms, the estate of Colonel Archibald Rogers. This property occupies more than a mile of frontage on the east bank of the Hudson River in Dutchess County, New York, about five miles north of Poughkeepsie and a mile south of Hyde Park. It is traversed by the Albany Post Road.

GEOLOGY AND SOILS

The forest lies in the Taconic geographic province of New York, a region of markedly folded strata (Tarr, 1902). It is underlaid by the Hudson River series of rocks, which are of sedimentary origin and the Silurian age, consisting of slates, shales, grits, limestones, and siliceous and calcareous breccias and conglomerates. In their stratification the beds alternate a great many times without any regular sequence. Within the area occupied by this woodland the rocks are mostly grits so tilted as to form almost vertical strata. The soil, Dutchess stony loam, is largely derived from the underlying rock or from rock of similar character which has been transported very little by glacial action. It is a fine-textured loam, which, tho high in silt content, includes sufficient sand and fine gravelly fragments to make it granular and friable (Mooney and Belden, 1909). Angular rock fragments or slabby pieces of the underlying thin-bedded sandstones and grits occur on the surface and within the soil.

Author's acknowledgments. In presenting the results of a study based on the remeasurement of sample plots established twenty years ago, the writer wishes to express appreciation to Colonel Archibald Rogers, owner of the forest in which the plots were located, for his kindness in permitting him to make the remeasurements and in lending his copy of the working plan for the forest, which contained personal notes of great value. The writer wishes to acknowledge also the generosity of the United States Forest Service in lending original field data and in permitting the use of photographs.

Uneven weathering of the upturned strata has developed long ridges running north and south, between which small swampy areas are frequently found. The surface is therefore very uneven and is marked by a series of disconnected, irregular, rocky ridges in which the underlying rock is generally exposed. The unevenness of the topography and the granular character of the soil result in good surface drainage except at the low points where there are no outlets. The soil depth varies from only a few inches on the ridges to three feet or more in the miniature valleys between. The average soil depth is less than eighteen inches. The land is undoubtedly absolute forest land because of its stony character and uneven surface.

FOREST TYPES

In a classification of the forest regions of the United States, a part of the sprout hardwood type of the Central Hardwood Region is shown to extend up the Hudson River Valley (Anonymous, 1910). Crumwold Forest falls within this area. In order to discuss adequately the results obtained in the present study, it was necessary to conform to the classification of stands used in taking the original records. The types to be considered are white oak, chestnut oak, and hardwood swamp (figure 1). The existence of three distinctly different associations on so small an area, embracing but a single soil type and with no significant differences in elevation, must be explained almost wholly on the basis of soil depth and moisture content.

The white oak type

All of the woodland classified as of the white oak type occurs on an area east of the Albany Post Road, at the highest elevation and farthest from the river. Here the soils are uniformly deeper than near the river. The rocky ridges are broader, less numerous, and usually covered with a soil mantle from six to eighteen inches deep. In consequence the moisture content of the soil is relatively high. The predominating species, listed in the order of their importance, are white oak, black oak (and scarlet oak also), chestnut oak, and hickories. Other species present are basswood, beech, black ash, black birch, black cherry, black locust, blue beech, butternut, chestnut, elm, flowering dogwood, gray birch, hemlock, hop hornbeam, large-toothed aspen, red cedar, red maple, sassafras, sugar maple, swamp white oak, white ash, white mulberry, white pine, and yellow birch. In 1905 it was found that 74.5 per cent of the trees present in this type were of sprout origin (Peters, 1905). The relative volume percentages of the different species are shown in table 14 (page 32).

The chestnut oak type

The chestnut oak type is confined to that part of the forest near the river where the ridges (from fifteen to forty feet in height) formed by uneven weathering of the upturned rock strata are most numerous. These form an almost unbroken series, with frequent rock outcroppings. Here the soil mantle is thinner than on areas bearing stands of the white oak type, and is therefore relatively dry, especially on the slopes and the tops of ridges. Representative examples of the chestnut oak type are shown in figures 2 and 7. The predominating species of this type are chestnut oak, red oak, white oak, and hickories. Other species present are basswood,

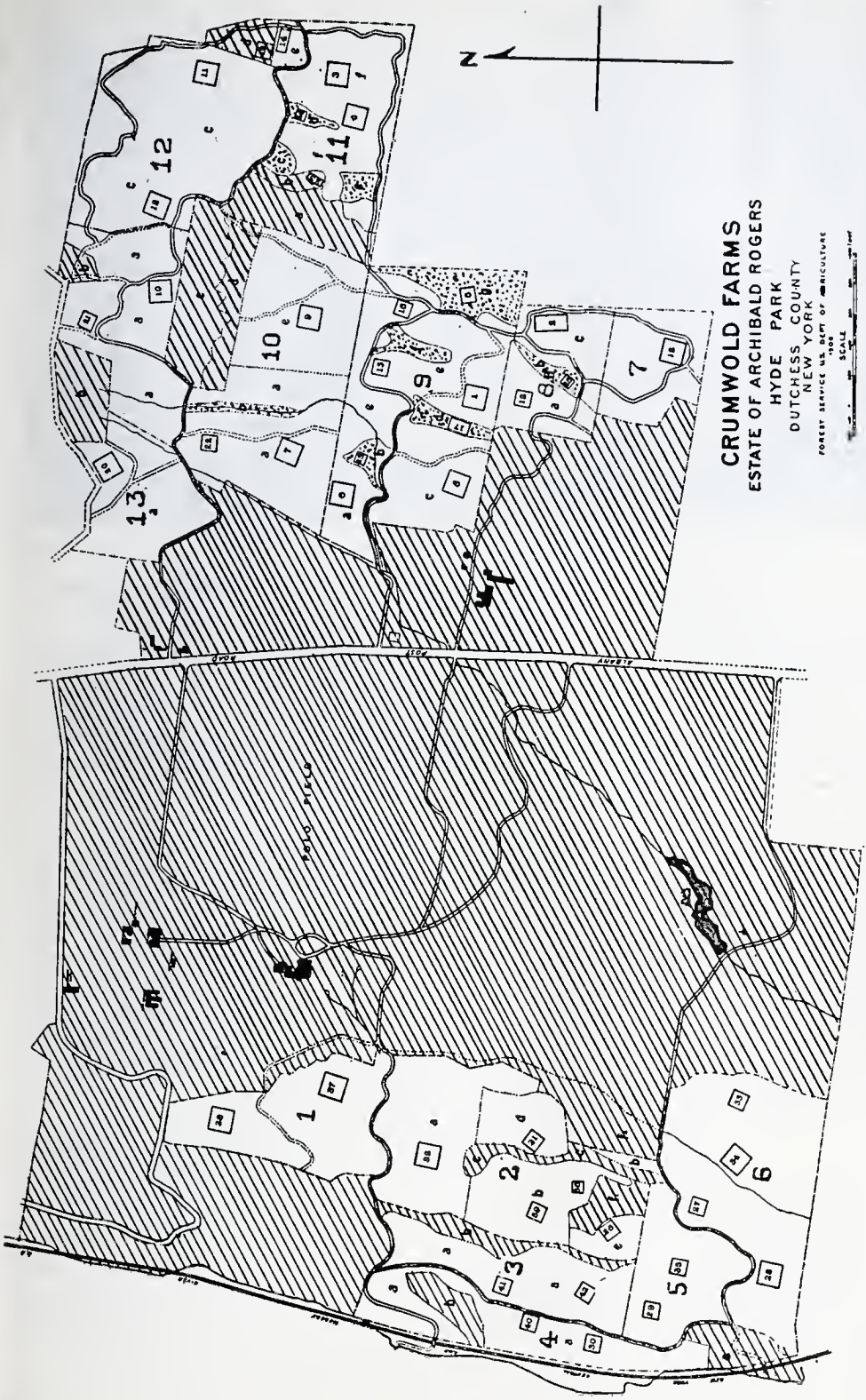

FIGURE I. DIVISION OF CRUMWOLD FOREST INTO COMPARTMENTS AND SUBCOMPARTMENTS, AND LOCATION OF SAMPLE PLOTS
Unshaded areas are the white oak and chestnut oak types; stippled areas are the hardwood swamp type; hatched areas are non-wooded

FIGURE 2. REPRESENTATIVE STAND OF THE CHESTNUT OAK TYPE
The photograph shows the nearly vertical outcropping rock strata on the right. This is in compartment 5, near plot 35

beech, black ash, black birch, black cherry, black locust, black oak, butternut, chestnut, elm, gray birch, hemlock, hop hornbeam, red cedar, red maple, sassafras, sycamore, tulip, and white ash. In 1905 it was found that 87.3 per cent of the trees present in this type were of sprout origin (Peters, 1905). The relative volume percentages of the different species are shown in table 14 (page 32).

The hardwood swamp type

All of the hardwood swamp areas of sufficient size to be segregated as such in the classification of forest types, occur east of the Albany Post Road. These areas are surrounded by stands of the white oak type. In the original classification two swamp types were recognized. One, the swamp white oak type, contained swamp white oak as the predominant species, while the red maple swamp type was predominantly red maple. That each of these types contains numerous trees of the species characteristic of the other type is shown by a tabulation of the average percentages of each species present in 1905 (Peters, 1905):

	Swamp white oak (per cent)	Red maple (per cent)	Elm (per cent)	Other species (per cent)
Swamp white oak type	27.8	19.8	12.1	40.3
Red maple swamp type	9.0	50.0	9.9	31.1

Where swamp white oak predominated, the areas unquestionably were originally somewhat drier than the sites classed as the red maple swamp type. However, the differences were not great, and it seems probable that most of the swamp areas were intermediate between the true red maple type and the true swamp white oak type. Furthermore, just prior to 1905, drainage ditches which operated to equalize moisture conditions

were extended into each of the swamp areas. Therefore, for the purpose of this study it was deemed advisable to combine the swamp areas in a single type designated as hardwood swamp. In this hardwood swamp type, swamp white oak, red maple, and elm predominate. Other species present are beech, black ash, black birch, black oak, butternut, chestnut oak, pignut hickory, shagbark hickory, white oak, and white pine.

METHOD OF STUDY

ESTABLISHMENT OF PLOTS IN 1905 [1]

The sample plots on which the present study is based were originally established as guides to assist the owner in the improvement of this woodland, not for a scientific study of growth. The work was done early in the summer of 1905. At least one plot was laid out in each subcompartment of Crumwold Forest. The purpose in establishing the plots was to give the owner concrete examples to be followed in carrying out cutting operations on the forest. The respective plots were selected as being representative of average conditions on the area for which they were to serve as cutting guides, and were given appropriate silvicultural treatment. Inasmuch as certain of the subcompartments for which plots were provided would not be operated until the close of a fifteen-years working period, each plot was made permanent by setting a black-locust post at each of the four corners. Of a total of forty-three plots, seventeen were one-half acre in area, twenty-one were one-quarter acre, and five were one-eighth acre. Four of the eighth-acre plots represented the hardwood swamp type, which occurred in areas so small as to make larger plots impracticable. The plots are enumerated in table 1.

After the plots were laid out, trees were marked for removal and data for each plot were taken as follows: (1) a tally, by inch-diameter classes, of all trees one inch and more in diameter breast-high, to be left on the plot; (2) a tally, by inch-diameter classes, of all trees marked for removal; (3) a forest description, including altitude, slope and aspect, rock and soil characteristics, depth of litter and humus, enumeration of species forming ground cover, underbrush, and reproduction, notes on silvicultural condition, merchantable condition, and damage, and age of stand. A description of the nature and the purpose of the cutting to be made was included on the tally sheet for each plot. In tallying the trees on the plots, their origin, whether sprout or seedling, was indicated by the use of blue pencil for tallying sprouts and black pencil for tallying seedlings. Dead trees marked for removal were further differentiated by the use of a red pencil in tallying. In the white oak type the important species — white oak, black oak, chestnut oak, and hickory — were tallied separately. Other species were grouped in a single classification designated as "Others." In the chestnut oak type the important species tallied separately were chestnut oak, red oak, white oak, and hickory. Swamp white oak, red maple, and elm, only, were tallied by species in the hardwood swamp type. The cutting of all trees marked for removal was done under the direct supervision of Forest Service men. The nature of the cuttings is described and discussed under "Silvical Effects of Cuttings" (pages 30 to 46).

[1] By cooperative agreement between the owner and the United States Forest Service, J. Girvin Peters, then forest assistant in the Forest Service, prepared "A Working Plan for the Woodland on Crumwold Farms, the Estate of Archibald Rogers, Hyde Park-on-Hudson." The sample plots on which the present study is based were laid out by Mr. Peters as incidental to placing Crumwold Forest under management.

TABLE 1. ENUMERATION OF SAMPLE PLOTS

Sample plot no.	Forest type	Plot area (acres)	Age in 1905 (years)	Cutting in 1905*	
				Kind	Remarks
1	White oak	0.5	60	Improvement	Moderate
2	White oak	0.5	70	Improvement	Heavy
3	White oak	0.5	70	Improvement	Moderate
4	White oak	0.5	75	Improvement	Light
5	Red maple	0.25	45	Improvement	Light
6	White oak	0.5	65	Improvement	Light
7	White oak	0.5	65	Reproduction	Shelterwood type; all hemlock removed
8	White oak	0.5	40	Improvement	Moderate
9	White oak	0.25	10	Cleaning	Chestnut sprouts and inferior species
10	White oak	0.5	75 and 35, two-storied	Improvement and thinning	Moderate
11	White oak	0.5	45–70, uneven	Improvement	Bushy pine removed
12	White oak	0.5	8	Liberation	Left-overs removed
13	Old field	0.25	1–6	Cleaning	
14	White oak	0.25	60–100	Reproduction	Light
15	White oak	0.25	65	Improvement	Moderate
16	White oak	0.25	65	Improvement	Oppressed trees removed
17	Swamp white oak	0.25	40	Improvement	Very light
18	White oak	0.5	10–40, uneven	Liberation	Larger trees removed
19	White oak	0.25	50–115, uneven	Improvement	Light
20	White oak	0.5	20–90, uneven	Reproduction and liberation	Heavy
21	White oak	0.25	70	Improvement	Heavy
22	White oak	0.25	60	Improvement	Moderate
23	Chestnut oak	0.125	65–85, uneven	Improvement	Light
24	Swamp white oak	0.125	70	Reproduction	Light
25	Red maple	0.125	65	Reproduction	Very light
26	Chestnut oak	0.25	100	Improvement	Moderate
27	Chestnut oak	0.25	75 and 30, two-storied	Improvement	Light in under story
28	Chestnut oak	0.5	75 and 30, two-storied	Improvement	Moderate
29	Chestnut oak	0.25	80	Improvement	Light
30	Chestnut oak	0.25	65	.....	No cutting
31	Chestnut oak	0.25	90	Reproduction	Light, many-cut shelterwood
32	Chestnut oak	0.5	90	.....	No cutting
33	Chestnut oak	0.25	30–75, uneven	Improvement	Oppressed trees removed
34	Chestnut oak	0.5	75 and 30, two-storied	Improvement	Oppressed trees removed
35	Chestnut oak	0.25	80	Improvement	Light
36	Chestnut oak	0.125	85–150, uneven	Reproduction	Moderate
37	Chestnut oak	0.5	1–100, uneven	.....	No cutting
38	Chestnut oak	0.5	1–100, uneven	.....	No cutting
39	Chestnut oak	0.25	55–155, uneven	Reproduction	Heavy, much hemlock
40	Chestnut oak	0.25	65	.....	No cutting
41	Chestnut oak	0.25	1–20	.....	No cutting
42	Chestnut oak	0.25	1–20	.....	No cutting
43	Swamp white oak	0.125	30	Improvement	Light

* The classification of cuttings and the remarks are those of the author, based on the original tally sheets. They do not agree in all instances with the Forest Service classification of the cuttings, which recognized only "improvement thinnings" and "reproduction cuttings."

REMEASUREMENT OF PLOTS IN 1925[2]

At the time of remeasurement in 1925, forty-one of the forty-three original plots were located. One plot, no. 13, which was established in an open field slowly seeding to hardwood, was not remeasured, since during the intervening period the hardwood had been cleared away and a pine plantation established. In the remeasurement, all trees 0.6 inch and more in diameter were tallied by diameter and crown classes. For the sake of simplicity only three crown classes were recognized. They were dominant

[2]The remeasurement of sample plots was executed in July, 1925, by the author, assisted by A. A. Doppel, a graduate student in the Department of Forestry at Cornell University.

(into which co-dominants were thrown), intermediate, and overtopped. An estimate of the average total height of the trees in each crown class was obtained by measuring several individuals on each plot. As in the work of 1905, the important species were tallied separately. The nature of the forest floor, the ground cover, the underbrush, reproduction, and the form and condition of the trees composing the stand, were studied.

GROWTH DATA

DIAMETER GROWTH OF OAKS

Method of computation

Diameter-growth data were obtained directly by the remeasurement of trees after a growth period of twenty years. The diameter increase could not, however, be recorded directly in the field, since no trees were numbered or otherwise identified on the sample plots. The individual trees could be identified only after all the trees on a plot had been remeasured. The diameter increase of the individual tree was determined in the office by a comparison of the original and the remeasurement tally. To illustrate the ease with which the individual trees were identified by comparison of the 1905 and 1925 tallies, the data for one sample plot are presented in table 2.

TABLE 2. COMPARISON OF 1905 AND 1925 TALLIES ON PLOT 32
(Area one-half acre)

Diameter breast-high (inches)	White oak		Chestnut oak		Red oak		Black oak		Hemlock		Miscellaneous	
	1905	1925	1905	1925	1905	1925	1905	1925	1905	1925	1905	1925
1	....	19	....	146	....	105	....	....	....	6	....	240*
2	....	....	....	6	....	13	....	....	....	2	....	45*
3	....	....	....	....	....	1	....	....	....	....	....	5*
4	....	....	....	....	....	....	....	....	....	....	....	....
5	....	....	....	....	....	....	....	....	....	....	1	1
6	....	1	....	....	....	....	....	....	1	....	....	....
7	....	....	....	....	1	....	....	....	....	....	....	1
8	....	....	....	....	....	....	....	....	....	....	1	....
9	....	....	....	....	....	....	....	....	2	1	1	....
10	....	....	....	....	....	....	....	....	....	....	....	....
11	1	....	....	....	....	....	....	....	....	2	....	2
12	2	....	1	....	1	....	....	....	....	....	1	....
13	1	1	....	....	2	1	....	....	....	....	....	....
14	2	2	1	....	2	....	....	....	....	....	....	....
15	....	1	....	1	3	2	....	....	1	....	....	....
16	1	2	....	....	....	2	....	....	....	....	....	....
17	....	....	....	1	2	1	1	....	....	1	....	....
18	1	....	....	....	....	2	....	....	1	....	....	....
19	....	1	....	....	....	2	....	1	....	....	....	....
20	....	1	....	....	....	....	....	....	....	1	....	....
Total	8	28	2	154	11	129	1	1	5	13	4	294

* The miscellaneous species in the 1-, 2-, and 3-inch classes were as follows: hard and soft maple, 107; white ash, 72; black birch, 62; basswood, 20; beech, 16; hickory, 9; sassafras, 3; black cherry, 1; total, 290.

By comparing 1905 and 1925 tallies for any species, it will be seen that the diameter increase for the twenty-years period can be determined. For example, in white oak it will be seen that the eighteen-inch tree has attained twenty inches, the sixteen-inch tree has attained nineteen inches, and so forth. Or, if red oak is considered, it is seen that the two seventeen-inch trees have attained nineteen inches, and that of the three fifteen-

inch trees two have attained eighteen inches and the other one seventeen inches. Comparisons may be made of other species also. Similar comparisons may be made for a very young plot. The tallies for plot 9 (table 15, page 34) show diameter growth very plainly. In the case of white oak on plot 9, it is probable that the two three-inch trees grew to eight inches, while four of the two-inch trees grew to seven inches, seven of them to six inches, and the remaining seven to five inches. Of course the positive identification of every individual is not possible. Only those trees which could be identified with reasonable certainty were used in the study of diameter growth.

As has been stated, the origin of each tree, whether sprout or seedling, was indicated in the tallying on the original record. It was therefore possible to divide the trees of a given species into two groups, sprouts and seedlings. This was done when the tally sheets were compared. In the remeasurement of the plots the trees were tallied by crown classes. In selecting the trees on which the diameter-growth computations are based, all the trees other than dominants were eliminated. Data for white oak were derived from sample plots of the white oak type only, and data for red oak and chestnut oak were taken exclusively from chestnut oak sample plots.

The selected diameter-growth data obtained from the tally sheets were organized and averaged so that for each of the two growth forms of each

TABLE 3. DIAMETER GROWTH OF OAKS IN MANAGED STANDS

(Expressed as the number of years required to grow from one inch class into the next. Based on 535 carefully selected trees)

Diameter breast-high (inches)	Years to grow one inch from next lower diameter class					
	Red oak		White oak		Chestnut oak	
	Sprouts	Seedlings	Sprouts	Seedlings	Sprouts	Seedlings
1	4.6	8.7	5.2	10.5	5.8	11.7
2	4.7	6.1	5.4	7.8	5.8	8.0
3	4.8	5.1	5.5	5.9	5.9	6.1
4	4.8	4.5	5.7	5.2	6.1	5.3
5	4.8	4.1	5.8	4.6	6.1	4.8
6	4.8	4.0	5.9	4.6	6.3	5.0
7	4.8	4.0	6.1	5.0	6.5	5.2
8	4.9	4.1	6.4	5.3	6.7	5.6
9	5.1	4.4	6.7	5.8	6.9	6.2
10	5.3	4.7	6.9	6.3	7.5	6.9
11	5.6	5.0	7.1	6.7	8.6	7.7
12	6.0	5.3	7.6	7.1	10.0	8.7
13	6.5	5.7	8.3	7.6	11.4	9.8
14	7.4	6.5	.....	8.0	.....	.....
15	9.0	7.5	.....	.....	.....	.....
16	11.9	8.6	.....	.....	.....	.....
Total*	95.0	88.3	82.6	90.4	93.6	91.0

* The age of a tree when it has attained a given diameter may be ascertained by adding together the years required for it to grow from one inch class to the next, for all preceding inch classes. The totals here given represent the ages of the various species and growth forms when they have attained the highest diameters for which growth data are given.

species the diameter increase in inches over a period of twenty years was shown by inch-diameter classes. The number of years required to grow one inch was ascertained by dividing the average diameter increase for the period into the number of years in the period (twenty years). For example, the average diameter increase of a thirteen-inch red oak of sprout origin was 3.09 inches, and therefore the average thirteen-inch red-oak sprout required 6.47 years to grow one inch ($20 \div 3.09 = 6.47$). For each species and growth form, the values so obtained were plotted (average years to grow one inch, on diameter) and harmonized by a curve. The harmonized values as read from these curves are given in table 3. By cumulative adding of the values in table 3, the total age of the tree at each diameter was determined. Curves showing diameter growth (figure 3) were constructed by plotting on diameter the age values thus derived from table 3. These curves show for dominant trees the diameters attained at various ages. The black curves are the result of the present

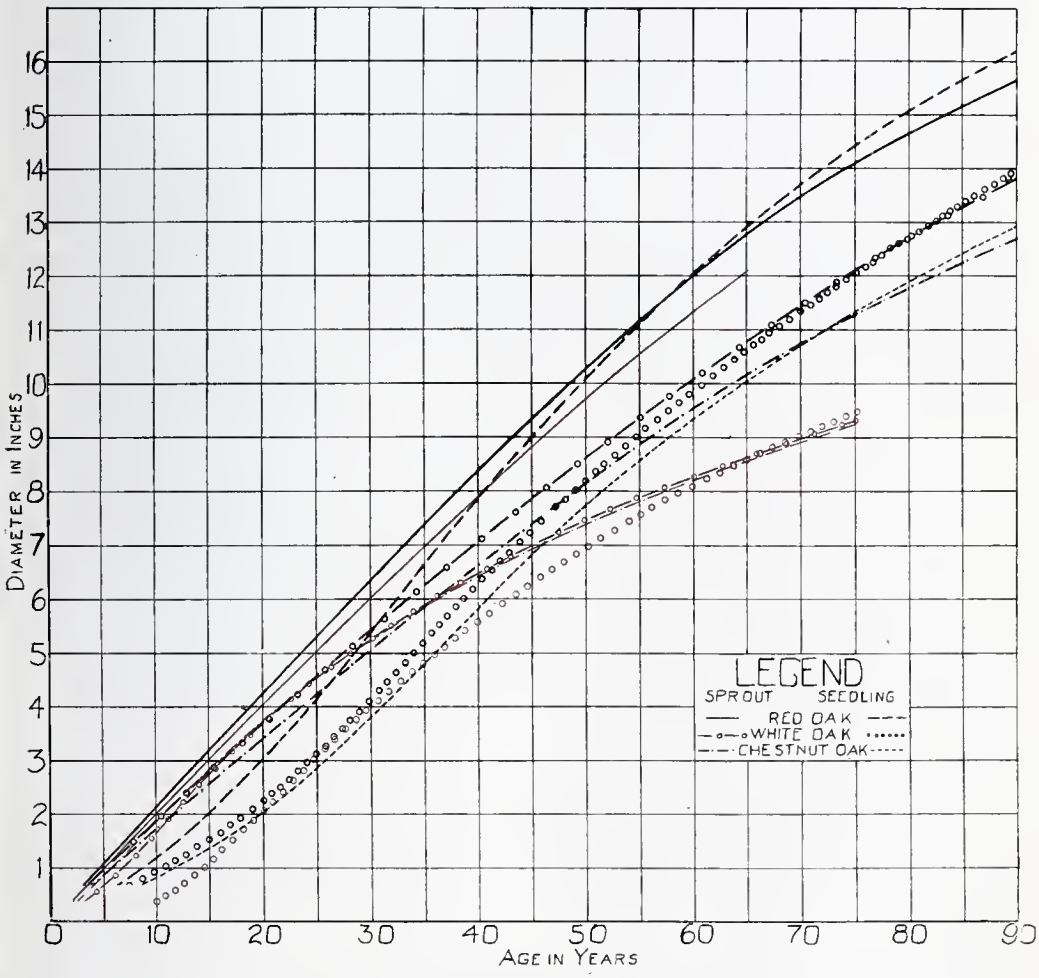

FIGURE 3. DIAMETERS ATTAINED AT VARIOUS AGES BY SEEDLINGS AND SPROUTS OF RED OAK, WHITE OAK, AND CHESTNUT OAK

The black curves show growth in managed stands, and the red curves growth in natural stands. The values for growth in natural stands were derived from data in the original working plan prepared by the Forest Service (Peters, 1905)

study and indicate the rate of growth of dominant trees in managed stands. The red curves show diameter growth of trees in unmanaged stands. They are based on a tabulation of diameter growth prepared by the United States Forest Service from stem analyses made on the sample plot in 1905.

Discussion of results

Several significant facts are revealed by the data in table 3 and the curves of figure 3.

1. A marked difference in general trend or configuration between seedling-growth curves and sprout-growth curves is observed. These differences are emphasized by a great similarity in the general character of curves representing the same growth form but different species. It is to be noted that sprouts invariably make their most rapid growth in youth and that the growth rate falls off slowly but steadily thruout the life of the tree. Seedlings, on the other hand, grow slowly during the early years, attain a very rapid growth rate during the period from fifteen to sixty years of age, and decline slowly in growth rate during the period from sixty to ninety years of age. These facts are neither new nor difficult to explain. The rapid growth in youth of trees of sprout origin may be accounted for by the existence of an established root system functioning to provide the new growth with abundant moisture and food materials. In contrast to this, the trees of seedling origin, in becoming established, must undergo a period of struggle and severe competition during which the root system is slowly developed until it can provide moisture and nutrients adequate to meet the needs of the trees in rapid growth. For this reason the growth of trees of seedling origin is slow at first. It will be observed that the general configuration of a seedling or sprout diameter-growth curve is the same whether the trees occur in natural or in managed stands.

2. For each of the species studied, there is an age at which the diameter attained by a tree of seedling origin equals that of a sprout. Thereafter diameters of seedlings exceed those of sprouts, but the differences in diameter attained by the different growth forms[3] are so slight that they are unimportant. In figure 3 it is seen that seedling diameters equal those of sprouts by the time the trees are fifty-five to seventy-five years old, depending on the species. In all cases, after the trees have reached ten inches in diameter differences due to the growth form are insignificant. This leads to the conclusion that, so far as rate of diameter growth is concerned, there is no choice between sprouts and seedlings if the diameters of trees cut are to exceed ten inches. Other factors may indicate that preference should be given to one or the other growth form.

3. A prolongation of rapid diameter-growth rate due to improvement cuttings and reproduction cuttings is clearly indicated in figure 3. This extension of the period of rapid diameter growth in managed stands results in the attainment of larger diameters at a given age in such stands

[3] Except where specific mention is made of single and multiple seedling sprouts, these forms are classed with seedlings. The author has accepted the classification of growth forms presented by Leffelman and Hawley (1925), which defines the various growth forms as follows: "(1) A sprout is a tree which has grown from a stump over two inches in diameter at the ground line. (2) A seedling is a tree grown from a seed. (3) A single seedling sprout is a tree with a single stem which has grown from a stump two inches or less than two inches in diameter at the ground line. (4) A multiple seedling sprout is a tree with more than one stem, which has grown from a stump two inches or less than two inches in diameter at the ground line."

than are reached by trees in natural stands. One must remember that the data on which these curves are based were taken from the records of sample plots most of which were even-aged. Thus the diameters of small trees in managed stands were derived from young plots on which little cutting had been done. This is desirable, as, in practice, improvement cuttings, thinnings, and reproduction cuttings will not be carried out in even-aged stands under thirty years of age. Since little cutting had been done in the stands from which the growth data for trees up to six inches in diameter were obtained, one would expect the values derived from the measurement of trees in these managed stands to vary but little from those derived by stem analyses in 1905. On examination of the sprout-growth curves in figure 3, it is seen that there are no essential differences between the black and the red curves up to the thirtieth year, at which time the trees have reached five to six inches in diameter. In other words, management in this case begins after the stands have passed their thirtieth year, so that the early growth of trees in stands to be managed later is really that of trees in natural stands. Soon after the thirtieth year the two curves representing trees of the same species and growth form begin to diverge rapidly. This divergence is the result of the sustained diameter growth of the trees in managed stands. For the types and species studied, the divergence is least in the case of red-oak sprouts. Red oak is the most rapid-growing species present in the chestnut oak type. On this forest it surpasses its associates not only in diameter growth but also in height growth, as is clearly shown by stem analyses of trees cut.[4] Because of its greater height growth, red oak in natural, even-aged stands of the chestnut oak type easily attains a dominant or super-dominant position and retains this position thruout the life of the stand. Trees of this species are therefore comparatively free from crown competition with other species. This fact is sufficient explanation for their superior ability to maintain rapid diameter growth in natural stands. Since rapid diameter growth is maintained in natural stands, the effect of silvicultural treatment on this species will necessarily be less pronounced than in the case of associated species the diameter growth of which is greatly reduced by competition in natural stands.

Reduction of the time required to produce trees of merchantable size is one of the chief aims of silvicultural management. As has been noted, a comparison of the growth curves (figure 3) shows that thru silvicultural treatment the forest has been made to produce trees of given merchantable diameters in less time than is required for them to attain these diameters in natural stands. Unfortunately the stem analysis on which the growth curves for trees in natural stands are based, did not include a sufficient number of large-sized trees to enable one to extend the growth curves for white oak and chestnut oak beyond the seventy-fifth year. At that age they had attained a diameter of 9.3 inches. In managed stands this diameter was reached by white oak in fifty-five years and by chestnut oak in fifty-nine years — twenty and twenty-four years, respectively, less than the time required in natural stands. The general trend of the curves indicates, however, that thru management the period required

[4] Leffelman and Hawley (1925) found that chestnut oak exceeded red oak in mean annual height growth on Sites II and III in Connecticut, both for four-years-old stems and for larger advance growth after release by a final cutting.

to attain merchantable diameters of twelve inches and more in this case will have been reduced at least from thirty to fifty years. Similar reduction may be expected where analogous cuttings are made in like stands.

VOLUME GROWTH OF SAMPLE PLOTS

The per-acre volumes on the various sample plots, classified according to forest types, are given in tables 5, 6, and 7. They are represented graphically in the diagrams which accompany these tables — figures 4, 5, and 6, respectively. Average periodic annual increments for the various forest types, derived from the sample-plot volumes, are given in table 8.

Computation of volumes

The volumes removed from the sample plots in cutting, those remaining on the plots in 1905 after cutting, and those present in 1925 after twenty years growth, were computed separately for each plot.

At the time when the plots were established, local volume tables for the various species were constructed. These were based on a large number of stem analyses made of trees cut on the sample plots, in the adjacent woodland, and on the near-by estate of J. S. Huyler. These tables were used in computing the volume data presented in the working plan for the forest, but were neither of broad enough scope nor of sufficient accuracy for use in the present study. Therefore, in the preparation of the tables and diagrams herein presented, all 1905 volumes, as well as those of the remeasurement date, were computed from the original tally sheets. From a detailed study of several methods of volume determination, including many volume tables and several mathematical formulae, it was concluded that the best results for this study would be obtained by the use of the standard volume tables listed in table 4.[5] By the use of these tables, volumes on each of the sample plots were computed separately and raised to an acre basis.

TABLE 4. VOLUME TABLES USED IN THE COMPUTATION OF DATA

Species	Table nos.	Title of publication
White oak Chestnut oak Swamp white oak	40, 44	Second-growth hardwoods in Connecticut. U. S. Dept. Agr., Forest Service, Bulletin 96. 1912.
Red oak Black oak Scarlet oak	39, 43	
Hickory	7	The commercial hickories. U. S. Dept. Agr., Forest Service, Bulletin 80. 1910.
All other species	37	The northern hardwood forest. U. S. Dept. Agr., Bulletin 285. 1915.
	16	Forest mensuration. Massachusetts Dept. Conservation. 1921.

[5] All computations had been completed and this manuscript was nearly ready for the press before the appearance of Bulletin 17 of the Yale Forest School (Hawley and Wheaton, 1926). If the tables therein contained had been available to the author when the computations were undertaken, they would have been used for the computation of volumes.

For each of the oak species, it was possible to compute total-cubic-foot volume, total-board-foot volume, and the additional-cubic-foot volume remaining after the cubic-foot equivalent of board-foot volume had been deducted. Board-foot volumes were computed for all trees nine inches and more in diameter breast-high.

For hickory, only the total-cubic-foot volume was determined. This seemed justified by the fact that very little of the hickory attained saw-log size.

As has been stated previously, all species other than oaks and hickories were grouped together for the purpose of volume determination. The justification of this procedure is the writer's conclusion, based on a study in central New England, that in even-aged second-growth hardwood stands " the volume of a tree of given height and diameter in cords and cubic feet is the same regardless of species " (Spaeth, 1920). This does not mean that the individual trees in even-aged second-growth stands have the same form, but rather that the average form of a number of individuals is independent of species. The applicability to miscellaneous second-growth hardwoods, of the table used in the present study for the determination of the cubic-foot volume of this group, was demonstrated by the author on the Harvard Forest by a simple test.[6]

Each of the three tables (5, 6, and 7) presents, for one forest type, volume data concerning the sample plots of that type. Volumes in total cubic feet, total board feet, and additional cubic feet, are given for trees removed in cutting, the stand remaining after cutting, and the stand in 1925, twenty years after cutting. The average volumes for the type, as derived from the sum of the individual sample-plot volumes, are shown also.

All of the volume information available is presented in these tables. However, the significant facts concerning volume growth are disclosed only after careful study of the tables. In order to reveal these facts more vividly, the data are shown graphically in figures 4, 5, and 6. In each of these diagrams the individual plots are represented by figures of equal width. The height of the figures represents their per-acre volume. The plots are arranged in a series from left to right in the order of the magnitude of their 1905 volume. The volume after cutting in 1905, and the 1925 volume, are plotted on the same base. That part of the figure representing the 1905 volume is differentiated by crosshatching. The total-cubic-foot and total-board-foot volumes in 1925 are greater than those of 1905 by an amount equal to the net growth during the twenty-years interval. On the diagrams this total net growth is represented by the white part of the figure, that is, by that part of the 1925 volume which is in excess of the 1905 volume. The volumes removed from the plots by cutting in 1905 are represented to the same seale, but on a different base, directly over the 1905 and 1925 volumes of corresponding plots. Frequently the 1905 volume in additional cubic feet is greater than the 1925

[6] One-quarter acre was staked off in a twenty-eight-years-old even-aged hardwood stand. Of the total volume of this stand, 78 per cent was made up of red oak, red maple, chestnut, and yellow birch, and the remaining 22 per cent of miscellaneous species. All of the trees were tallied in inch diameter classes. The cubic-foot and cord volumes were computed by means of the table. The stand was then carefully cut and stacked in cord piles. The actual volume of the wood cut on the quarter acre was determined by measurement of the stacked wood. The volume as determined from the tally of standing trees by use of the volume table varied only 0.83 per cent from the actual measured volumes of the cut trees. This test is taken as sufficient evidence that the table is suitable for use in determining the cubic-foot volumes of trees grouped together under the caption " Other species." Since very few saw-log species occur in this group, only cubic-foot volumes were determined for it.

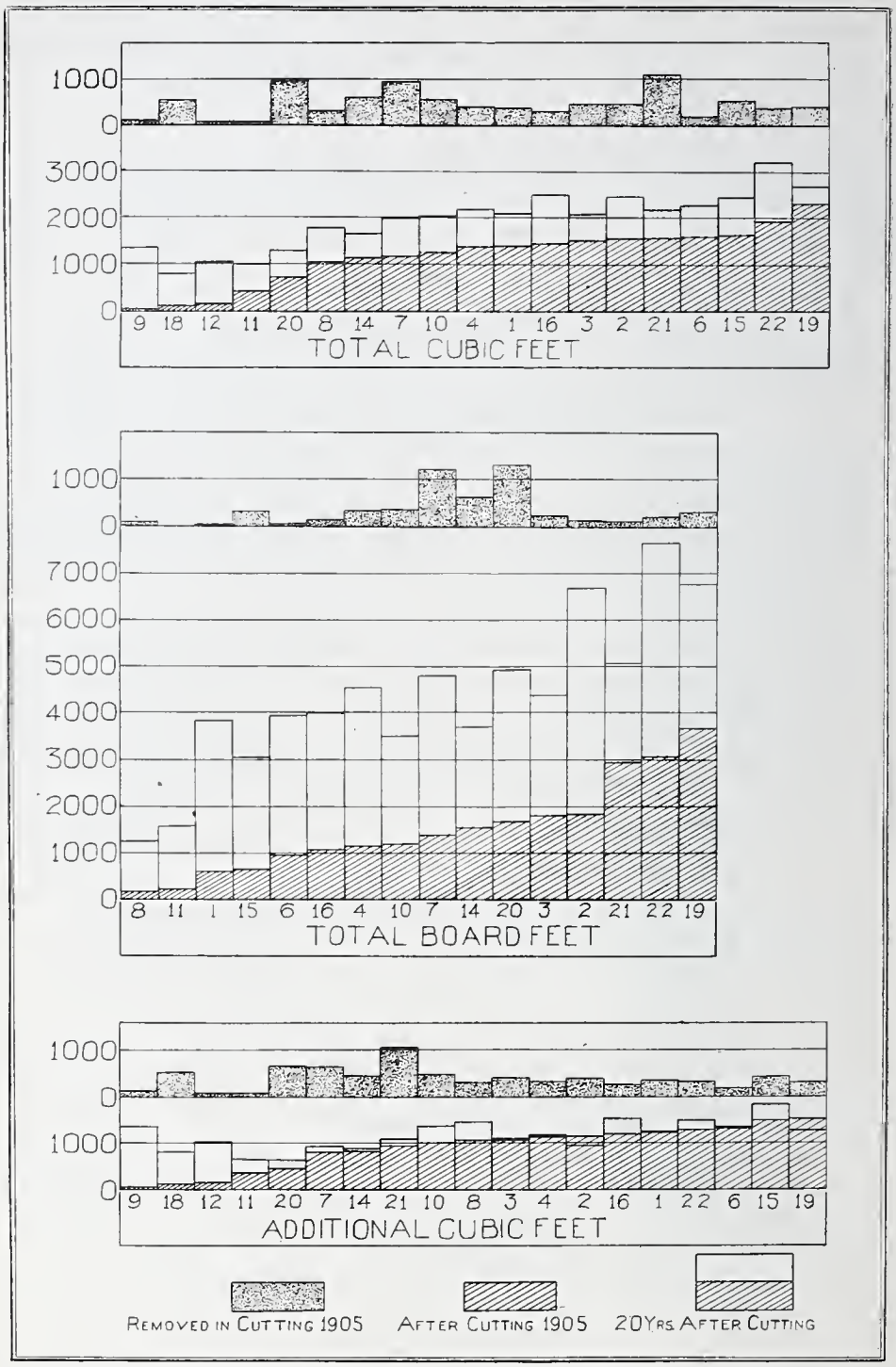

FIGURE 4. VOLUME GROWTH PER ACRE IN CUBIC FEET, BOARD FEET, AND ADDITIONAL CUBIC FEET ON SAMPLE PLOTS, WHITE OAK TYPE

volume. (An explanation of this is given on pages 21 to 22.) Wherever this occurs, a horizontal line within the crosshatched area indicates the 1925 volume. The part of the crosshatched area above this line represents the net loss in additional-cubic-foot volume during the growing period.

Periodic annual increment is the increment of a tree or a stand for a specified period divided by the number of years in the period. Maximum, minimum, and average periodic annual increments, in cubic feet and board feet, are shown for each forest type in table 8. The values in this table were derived directly from tables 5, 6, and 7. The net growth for the period was obtained from these tables by subtracting the 1905 volumes from the 1925 volumes. The periodic annual increment was determined by dividing this net growth by the number of years in the growing period. The maximum and the minimum for each type are those of the individual plots making the greatest growth and the least growth, respectively. The average periodic annual increment for each type is based on a summary of the growth of all plots representing that type.

The effects of silvicultural treatment on the volume growth of the various forest types during the twenty-years period ending in 1925 cannot be shown quantitatively. If the sample plots had been established originally for the purpose of determining the effects of the cuttings upon increment, untreated plots would have been established. It would then have been possible, by comparison, to show what proportion of the increment on each plot could be attributed to the silvicultural treatment. But since there were no control plots we have no knowledge of what the growth on uncut areas would have been. In the case of diameter growth we had definite information concerning the growth rates of the various species on the plots before cuttings were made. Differences between these diameter-growth rates and those for the period following cuttings were considered to be the results of such cuttings.

TABLE 5. VOLUMES PER ACRE ON SAMPLE PLOTS, WHITE OAK TYPE

Sample plot no.	Removed 1905			After 1905 cutting			Twenty years after cutting		
	Cubic feet	Board feet	Additional cubic feet	Cubic feet	Board feet	Additional cubic feet	Cubic feet	Board feet	Additional cubic feet
1	370.2	28	361.2	1,408.0	600	1,254.8	2,102.6	3,856	1,262.6
2	465.0	134	417.8	1,572.2	1,820	1,152.2	2,485.2	6,688	956.6
3	469.5	244	409.5	1,534.8	1,818	1,106.0	2,089.4	4,396	1,086.0
4	402.1	330	324.9	1,404.8	1,198	1,151.4	2,193.4	4,540	1,182.2
6	215.9	28	206.9	1,600.4	964	1,346.0	2,271.4	3,958	1,320.0
7	933.4	1,223	636.4	1,196.2	1,408	813.4	2,007.2	4,804	932.2
8	328.4	90	308.0	1,084.0	144	1,061.2	1,801.4	1,240	1,483.0
9	114.0	.....	114.0	47.2	.....	47.2	1,350.2	.....	1,350.2
10	565.9	342	484.3	1,280.8	1,206	1,015.6	2,066.6	3,520	1,372.8
11	84.4	.....	84.4	438.8	208	348.8	1,003.0	1,588	643.0
12	89.7	.....	89.7	130.0	.....	130.0	1,046.6	94	1,025.8
14	593.9	624	445.5	1,191.6	1,560	836.4	1,685.6	3,716	873.6
15	540.9	320	464.1	1,635.2	650	1,505.6	2,447.6	3,048	1,865.6
16	303.0	120	273.0	1,444.0	1,648	1,218.0	2,498.4	3,984	1,543.6
18	534.8	.....	534.8	110.0	.....	110.0	813.2	.....	813.2
19	404.5	308	323.7	2,322.4	3,686	1,556.0	2,728.0	6,772	1,302.4
20	967.1	1,326	661.9	731.4	1,678	446.4	1,309.8	4,926	635.6
21	1,101.3	120	1,071.3	1,574.0	2,952	938.2	2,174.4	5,048	1,094.8
22	375.4	212	328.2	1,938.4	3,048	1,292.4	3,213.2	7,648	1,522.4
Total	8,859.4	5,449	7,539.6	22,644.2	23,988	17,329.6	37,287.2	69,826	22,265.6
Average	466.3	286.8	396.8	1,191.8	1,262.5	912.1	1,962.5	3,675:0	1,171.9

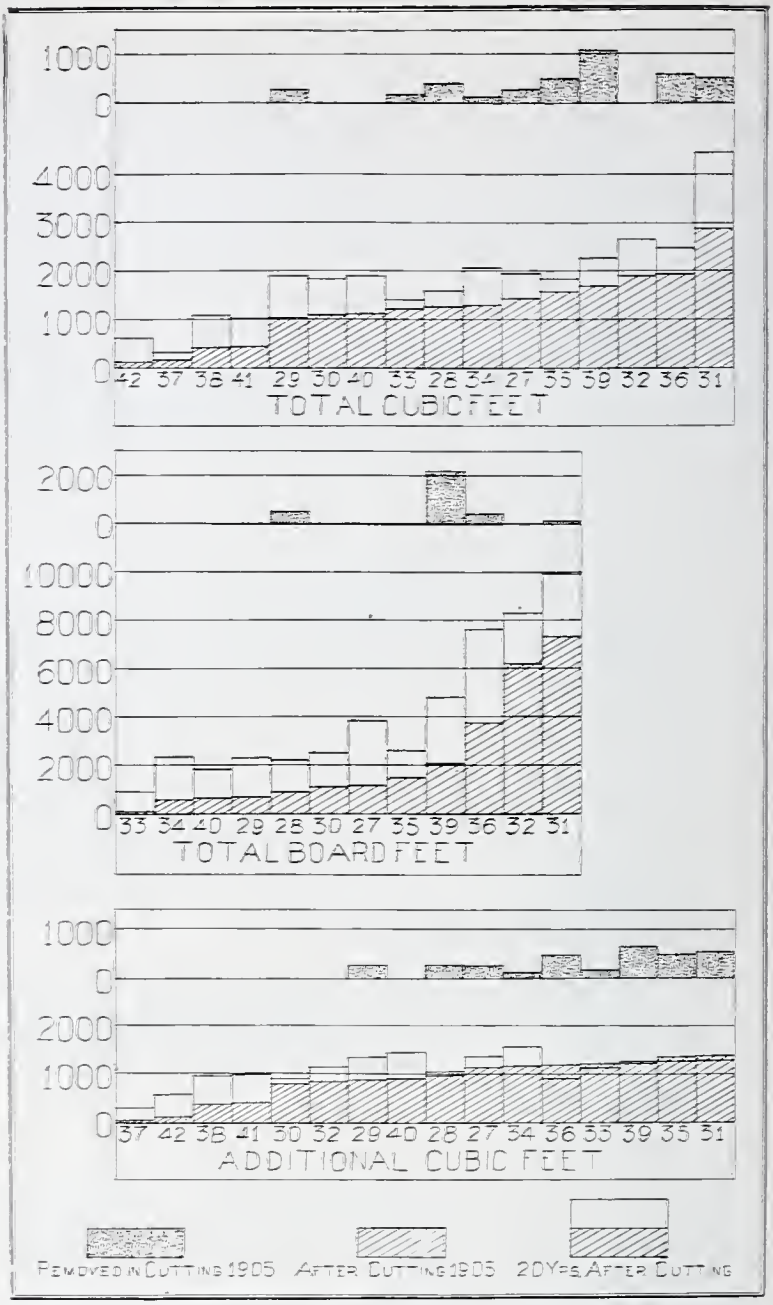

FIGURE 5. VOLUME GROWTH PER ACRE IN CUBIC FEET, BOARD FEET, AND ADDITIONAL CUBIC FEET ON SAMPLE PLOTS, CHESTNUT OAK TYPE

General discussion of volume growth

Many significant facts are brought out in the tables and diagrams showing sample-plot volumes.

On examination of those parts of figures 4 and 5 which portray total-cubic-foot and total-board-foot volumes, it is seen that there is, in general, no proportional relationship between the amount of growing stock present

TABLE 6. VOLUMES PER ACRE ON SAMPLE PLOTS, CHESTNUT OAK TYPE

Sample plot no.	Removed 1905			After 1905 cutting			Twenty years after cutting		
	Cubic feet	Board feet	Additional cubic feet	Cubic feet	Board feet	Additional cubic feet	Cubic feet	Board feet	Additional cubic feet
27	286.4	.....	286.4	1,422.4	1,160	1,136.4	1,958.0	3,860	1,340.8
28	408.3	482	292.3	1,261.6	912	972.6	1,583.4	2,266	1,044.6
29	277.9	.....	277.9	1,014.6	672	876.8	1,874.4	2,348	1,346.8
30	.....	.....	.....	1,076.2	1,104	814.6	1,822.4	2,556	920.4
31	536.8	120	533.8	2,888.8	7,304	1,358.2	4,455.2	9,876	2,450.4
32	.....	.....	.....	1,901.0	6,224	849.0	2,643.0	8,306	1,146.0
33	191.1	.....	191.1	1,202.4	72	1,183.2	1,386.4	896	1,125.6
34	134.5	.....	134.5	1,271.4	574	1,155.6	2,064.4	2,368	1,557.8
35	502.0	.....	502.0	1,569.2	1,508	1,352.8	1,820.0	2,628	1,240.0
36	597.4	400	491.8	1,929.6	3,784	1,176.0	2,473.6	7,632	909.6
37	.....	.....	.....	141.8	.....	141.8	305.4	.....	305.4
38	.....	.....	.....	390.0	.....	390.0	1,064.8	312	988.8
39	1,119.4	2,084	665.8	1,686.4	2,088	1,252.8	2,242.4	4,836	1,198.0
40	.....	.....	.....	1,083.8	624	891.8	1,803.2	1,848	1,455.2
41	.....	.....	.....	415.0	.....	415.0	1,007.2	.....	1,007.2
42	.....	.....	.....	120.0	.....	120.0	605.2	.....	605.2
Total	4,053.8	3,086	3,375.6	19,374.2	26,026	14,086.6	29,109.0	49,732	18,641.8
Average	253.4	192.9	211.0	1,210.9	1,626.6	880.4	1,819.3	3,108.2	1,165.1

at the beginning of the growing period and the volume increase during that period. Such a relationship would exist if the densities of the plots were approximately the same, in which case differences in 1905 volumes would closely parallel differences in age, and volume growth would vary in proportion to the normal current annual increment of the type. Such a proportional relationship would exist also if the plots were of approximately the same age, for in this case differences in volume would indicate differences in density. But where age and density are independent variables, present volumes are not indicative of growth potentialities. Plots 9 and 22 are both well stocked, tho their 1905 volumes place them at opposite ends of the total-cubic-foot volume scale (figure 4). Since their densities are equal, the wide difference in their 1905 volumes (table 5) reflects the difference in their ages, which are ten and sixty years, respectively. It was stated above that, when volume differences closely parallel differences in age, the volume growth varies in accordance with the normal current annual increment of the stand. The total-cubic-foot volume growth of the two plots during the period from 1905 to 1925 was almost indentical. The actual per-acre volume increases were 1303.0 cubic feet and 1274.8 cubic feet. It appears, therefore, that the periodic annual increments in cubic feet, over a twenty-years period, for ten-years-old and sixty-years-old stands are equal. This is possible, for the younger stand has not yet reached the period of most rapid cubic-foot volume growth, and the older stand is in the period of declining growth rate. (The board-foot volume growths of these two plots indicate entirely different characteristics for periodic annual increments in board feet, for the younger plot has produced no board-foot increment while the older plot has produced 4600 board feet per acre during the twenty-years growing period.) It would normally be expected that, in cubic-foot volume growth, some plots whose 1905 volumes lay between those of plots 9 and 22 would exceed them in growth. The fact that such is not

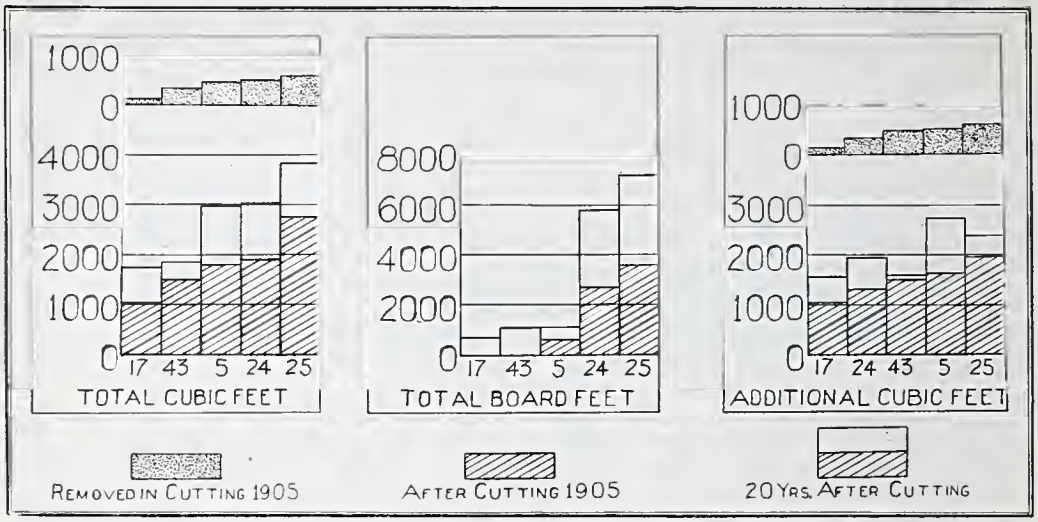

FIGURE 6. VOLUME GROWTH PER ACRE IN CUBIC FEET, BOARD FEET, AND ADDITIONAL CUBIC FEET ON SAMPLE PLOTS, HARDWOOD SWAMP TYPE

TABLE 7. VOLUMES PER ACRE ON SAMPLE PLOTS, HARDWOOD SWAMP TYPE

Sample plot no.	Removed 1905			After 1905 cutting			Twenty years after cutting		
	Cubic feet	Board feet	Additional cubic feet	Cubic feet	Board feet	Additional cubic feet	Cubic feet	Board feet	Additional cubic feet
5.....	488.7	.....	488.7	1,795.6	632	1,627.2	2,987.2	1,112	2,726.4
17.....	126.9	.....	126.9	1,030.0	.....	1,030.0	1,733.6	720	1,552.4
24.....	513.2	.....	513.2	1,926.4	2,708	1,303.2	3,258.0	5,808	1,945.2
25.....	596.8	.....	596.8	2,770.4	3,652	1,956.8	3,849.6	7,192	2,384.8
43.....	325.6	.....	325.6	1.505.6	.....	1,505.6	1,858.4	1,120	1,580.0
Total..	2,051.2	.....	2,051.2	9,028.0	6,992	7,422.8	13,686.8	15,952	10,188.8
Average	410.2	.....	410.2	1,805.6	1,398.4	1,484.6	2,737.3	3,190.4	2,037.8

the case is because few of these plots represent the ages at which normal current annual increments reach the maximum, and those which do represent these ages are decidedly understocked.

The volumes for 1925 in additional cubic feet are frequently less than those of 1905 altho total-cubic-foot volumes and total-board-foot volumes in every instance have made substantial gains. The principal reason for this is that certain trees which in 1905 were calculated in cubic feet only had attained saw-log size by 1925, and therefore not only the growth, but also a part of the volume formerly expressed in cubic feet, was expressed in board feet in 1925. The loss in additional-cubic-foot volume was, of course, greatest for those plots on which the ratio of board-foot increase in proportion to the total-cubic-foot increase was greatest. A comparison of plots 19 and 22 illustrates this principle. The board-foot increase of plot 19 (3086 board feet) was 67.1 per cent as great as that of plot 22 (4600 board feet); but the total-cubic-foot increase of plot 19 (405.6 cubic feet) was only 31.8 per cent as great as that of plot 22 (1274.8 cubic feet). With a gain in board feet 67.1 per cent as great as that of plot 22 and a gain in total cubic feet only 31.8 per cent as great, plot 19 suffered

a loss in additional-cubic-foot volume amounting to 253.6 cubic feet, while plot 22 made a gain of 230 cubic feet. That is, on plot 19 the board-foot increase, tho actually less than that on plot 22, was greater in proportion to the total-cubic-foot increase and resulted in a loss in additional cubic feet; while, conversely, on plot 22 a large board-foot increase accompanied by a disproportionately large total-cubic-foot increase resulted in a gain in additional cubic feet. On the youngest plots (figure 4, plots 9, 18, and 12, and figure 5, plots 42, 37, 38, and 41), gains in additional cubic feet were the same as those in total cubic feet, because there were no board-foot volumes present.

It will be noted that the plots, when arranged independently in the order of the magnitude of their board-foot volumes, do not fall into the same sequence as when arranged in the order of the magnitude of their total-cubic-foot volumes. The reason for this is that these volumes are in a large measure dependent on density rather than on age, and so the cubic-foot volume of a well-stocked young stand, containing few trees of sufficient size to yield a board-foot volume, may exceed that of an older stand in which the relative proportion of board-foot volume to cubic-foot volume is high. Plots 8 and 14 illustrate this principle in an excellent manner. In cubic-foot volume they were nearly equal, both in 1905 and in 1925. But plot 8 (forty years old in 1905) is a comparatively young stand, moderately well stocked, in which there is little saw-log material, while plot 14 (from sixty to one hundred years old in 1905) is a much older stand of relatively poor stocking in which most of the trees are of saw-log size. Therefore, when classified according to their board-foot volumes these plots are widely separated, whereas classification according to total-cubic-foot volumes brings them together (figure 4).

Periodic annual increment

White oak type

The average periodic annual increment in total cubic feet of the white oak type during the twenty-years growing period, 1905 to 1925, was 38.5 cubic feet (table 8). The maximum for any plot was 68.9 cubic feet.

TABLE 8. PERIODIC ANNUAL INCREMENTS OF SAMPLE PLOTS, BY FOREST TYPES

Forest type	Periodic annual increment, 1905 to 1925					
	Cubic feet			Board feet		
	Maximum	Minimum	Average	Maximum	Minimum	Average
White oak	68.9	20.3	38.5	243.4	0	138.1
Chestnut oak	78.3	8.0	30.4	192.4	0	74.0
Hardwood swamp	66.6	17.6	46.6	177.0	24.5	89.6

This maximum growth occurred on plot 22. The next highest increment was that of plot 9, which was 65.1 cubic feet. Plot 9 (age thirty years at the end of the growing period) was unquestionably fully stocked thruout

the growing period (figure 11 and tables 15 and 16). Its periodic annual increment must have been normal for the type at this age. In 1925 the total-cubic-foot volume of this plot was 1350.2 cubic feet (table 5) as compared with 1380 cubic feet, the normal yield of a second-growth hardwood stand of the same age as shown for Site Class II in a normal-yield table for second-growth hardwood stands in central New England, prepared by the author working on the Harvard Forest (Spaeth, 1920). This comparison would seem to indicate that the growth of the white oak type, as found here, is comparable to the growth of Quality II hardwood stands in central New England. A comparison of the periodic annual increment of plot 16 (age eighty-five years at the end of the growing period) with that of the normal stand as shown in the same table for the period from sixty-five to eighty years of age, further substantiates their similarity of growth, for the periodic annual increment of plot 16 is 52.7 cubic feet as compared with a yield-table value of 50.1 cubic feet. By comparing increments at extremes of the age scale we have demonstrated a similarity between the increments of well-stocked plots and those given for normally stocked natural stands. The average periodic annual increment of the type (table 8) is but 38.5 cubic feet, but we know that most of the stands on which this growth rate is based are greatly understocked. Furthermore, it may be expected that in the future the periodic annual increment of a given plot will equal or exceed the normal periodic annual increment for that age as derived from the yield tables. In this yield table the periodic annual increment in cubic feet is greatest for the preceding five-years period at the age of thirty-five years. At that age the periodic annual increment amounts to 85.6 cubic feet. The periodic annual increment obtained if we average together the periodic annual increments of a number of even-aged plots representing a wide range in age, will differ very little from the mean annual increment of the type. It may be expected, therefore, that as the density of these plots improves under silvicultural management, the mean annual increment will approach and ultimately exceed 55.0 cubic feet, which is the normal mean annual increment of natural stands as shown for Quality II sites in the table referred to above.

The average periodic annual increment of the white oak type in board feet was 138.1 feet. The normal mean annual increment derived from the table from which cubic-foot volumes were taken is 192.2 board feet. The periodic annual increment in board feet during the growth period was 72 per cent of the mean annual increment given in the yield table, while the periodic annual increment in cubic feet amounted to 70 per cent of the mean annual increment given in the yield table. In board feet, as in cubic feet, we may expect that the increment will ultimately exceed that of the fully stocked natural stand as given in the yield table. Plots 2 and 22 have the greatest periodic annual increments in board feet. These increments are 243.4 board feet and 230.0 board feet, respectively. The lower limit of the volume tables used in computing these sample-plot volumes was nine inches. During the growing period a large number of trees on these plots whose diameters in 1905 were less than nine inches, attained diameters of nine or more inches. This attainment of board-foot volume in 1925 by trees which were calculated only in cubic feet in 1905 accounts for the fact that increments of these plots were comparatively great. It is certain that their increments would have been even greater

had they been well stocked. This can easily be demonstrated, for it has been shown that the growth rate of this type corresponds to that of Site Class II in a standard second-growth-hardwood yield table. In 1905, plots 2 and 22 were seventy and sixty years old, respectively. Therefore their growth rate during the twenty-years period may be compared with that of this yield table for the period from seventy to eighty years of age, which is 267.0 board feet per acre per year. That the increments of these two understocked stands so closely approach that of a natural forest of normal density is due largely to the presence of a large amount of red oak, which is the fastest-growing tree of saw-timber species found in this forest. The periodic annual increment in board feet culminates at an age when large numbers of trees attain the lowest diameters for which board-foot volumes are calculated. A comparison of 1905 and 1925 tally sheets on white-oak plots indicates that for even-aged stands of this type the culmination occurs at about the seventy-fifth year.

Chestnut oak type

The average periodic annual increment for the chestnut oak type was 30.4 cubic feet. The maximum periodic annual increment was 78.3 cubic feet. The average cubic-foot increment was unquestionably below normal, due to the understocked condition of many of the plots. On the other hand, it is equally apparent that the maximum volume increase of 78.3 cubic feet is greatly in excess of what may be expected of normal stands of this type, even when fully stocked and subjected to proper silvicultural treatment, for the type occurs on dry sites with shallow soil where growth is necessarily slow. The abnormal periodic annual increment of 78.3 cubic feet which occurred on plot 31 may be accounted for in part by the fact that this plot is situated on a soil which is deeper and more moist than the average, but the fact that the plot contains an unusual

FIGURE 7. CHESTNUT OAK STAND OF THE BEST QUALITY, IN WHICH RED OAK IS ONE OF THE PRINCIPAL SPECIES (1925)

The cap (right foreground) is on a 17-inch red oak

amount of red oak, the fastest-growing of the species represented, is of far greater importance. The average percentage of red oak in the chestnut oak type is 31.9 per cent of the total cubic volume (table 14), but on plot 31 red oak in 1925 constituted 43.7 per cent of the total cubic volume. The general character of the better chestnut oak sites where red oak is abundant is shown in figure 7. In contrast, the poor, rocky ridges typical of this type where chestnut oak predominates, are exemplified by figure 2.

The characteristics of the periodic annual increments of the chestnut oak type in board feet are much the same as in cubic feet. The average, 74.0 board feet per acre per year, is much below normal, due to the understocked condition of the stands. The maximum, 192.4 board feet, which occurred on plot 36, is unquestionably also below normal, for the stand is decidedly understocked. In board feet the periodic annual increment of plot 31 was only 67 per cent of that of plot 36, while in cubic feet its periodic annual increment was 128 per cent of that of plot 36. These relationships are accounted for by the fact that on plot 31 a much greater proportion of the cubic-foot increase was of species for which no board-foot volume was computed.

Hardwood swamp type

The average periodic annual increment of the hardwood swamp type, 46.6 cubic feet, exceeds that of either of the other types. This should not, however, be interpreted as an indication that the increment of the swamp type normally exceeds that of the white oak type. The maximum periodic annual increment occurred on plot 24. Upon examination in the field this plot appeared to approach normal density, yet its periodic annual increment, 66.6 cubic feet, is exceeded by the maximum for the white oak type, 68.9 cubic feet, which in turn has been shown (page 22) to be below the normal periodic annual increment for the white oak type. The average periodic annual increment for the hardwood swamp type is 70 per cent of the maximum periodic annual increment, which approaches the normal; but the average periodic annual increment of the white oak type is only 56 per cent of the maximum, and this maximum is distinctly subnormal. From this it must be concluded that the average value for the hardwood swamp type is nearer the normal than is that of the white oak type. That the plots which form the basis for the determination of average periodic annual increment are individually and collectively nearer normal density in the case of the hardwood swamp than in the case of the white oak type, was clearly discernible by observation in the field. Typical stands of this type are illustrated in Plates III and IV.

The average periodic annual increment in board feet during the twenty-years growth period was 89.6 board feet. Board-foot increments of this type are low, because only one of the predominating species — swamp white oak — is considered as a saw-timber tree. The maximum board-foot increment of 177.0 board feet occurred on plot 25. This plot was well stocked and contained many swamp white oaks, which in 1905 were calculated in cubic feet only but which by 1925 had attained saw-timber sizes.

VOLUME GROWTH BY COMPARTMENTS

The volume growth by compartments was determined in order that the net result of silvicultural treatment might be judged. Compartment

volumes for 1905 and 1925 in total cubic feet, total board feet, and additional cubic feet, are here presented in tabular and graphic form. The periodic annual increment of the forest is shown by compartments.

TABLE 9. ENUMERATION OF SUBCOMPARTMENT AREAS INDICATING TO WHICH AREAS THE VARIOUS SAMPLE PLOTS ARE APPLICABLE

Compartment no.	Subcompartment		Compartment area (acres)	Sample plot no.
	Symbol	Area (acres)		
1	.....	11.0	.....	37
		6.5	.....	38
			17.5	
2	a	15.2	.....	32
	b	9.8	.....	39, 36
	d	4.1	.....	31
	e	2.5	.....	26
			31.6	
3	a	12.6	.....	41, 42
			12.6	
4	a	13.3	.....	30, 40
			13.3	
5	.....	12.0	.....	29, 35
			12.0	
6	.....	15.2	.....	27, 28
		13.7	.....	33, 34
			28.9	
7	.....	10.0	.....	18
			10.0	
8	a	4.9	.....	19
	b	1.1	.....	25
	c	5.9	.....	2
			11.9	
9	a	3.8	.....	6
	b	1.3	.....	43
	c	10.2	.....	8
	d	1.4	.....	17
	e	18.8	.....	1, 16, 15
	g	4.8	.....	5
			40.3	
10	a	17.6	.....	22, 7
	b	1.0	.....	.....
	e	13.6	.....	9
			32.2	
11	c	0.7	.....	.....
	d	0.7	.....	24
	e	0.8	.....	.....
	f	16.9	.....	3, 4
			19.1	
12	a	18.0	.....	10, 21
	e	30.2	.....	11, 12
	e	1.4	.....	14
			49.6	
13	a	12.3	.....	20
			12.3	
Total	.....	.....	291.3	

Method of determination

In the working plan of 1905, Crumwold Forest was divided into thirteen compartments. The boundaries of these administrative units were usually roads, property lines, or interior fences. Each stand within a compartment was designated as a subcompartment. In so far as possible, one or more sample plots were established in each subcompartment, or stand (figure 1). The areas of the compartments and the subcompartments are shown in table 9. This table and the map of Crumwold Forest (figure 1) show also which sample plots were located in each stand.

The total-cubic-foot, total-board-foot, and additional-cubic-foot volumes of each subcompartment were ascertained by multiplying the per-acre sample-plot volumes by the subcompartment areas. This was done for the trees removed in cutting, the volume in 1905 after cutting, and the volume in 1925 after twenty years growth. Where more than one sample plot occurred in the same stand, the per-acre volumes were averaged. The compartment volumes given in tables 10, 11, and 12 are the sums of these subcompartment, or stand, volumes. The sample plots were carefully chosen so that they would represent average conditions on their respective subcompartments. Their total actual area amounted to nearly five per cent of the forest area. This means that the compartment volumes have been determined on the basis of data which are equivalent to an extremely accurate five-per-cent cruise. On this basis compartment volumes are not necessarily exact. This is not important, for they must certainly approximate the actual volumes. Relative volumes and changes in volume due to growth are the prime considerations. These are shown with a high degree of accuracy because their determination is based on the remeasurement of identical areas.

Compartment volumes are shown diagramatically in figures 8, 9, and 10. In each of these figures the compartments are arranged from left to right in numerical order. The width of a compartment on the horizontal base is proportional to its area. The height represents its per-acre volume. Since the areas are the product of height and width, which in turn represent stand per acre and area in acres, respectively, these areas represent the actual volumes of the compartments. The volume in 1905 after cutting and in 1925 after twenty years growth are plotted on the same base. The 1905 volume is crosshatched to differentiate it from the greater 1925 volume. That part of the 1925 volume which is in excess of the 1905 volume represents net growth. On the diagrams it appears as a white block. The theoretical volumes removed in cutting in 1905 are represented on a different base directly above their respective 1925 compartment areas.

Periodic annual increments in total cubic feet, board feet, and additional cubic feet are shown in table 13. These values were derived for each compartment separately, by dividing the difference between the 1925 and 1905 per-acre average volumes by the number of years in the growing period.

Discussion of results

The difference in periodic annual increment between compartments composed of stands of the white oak and swamp hardwood types and those containing the chestnut oak type only, is perhaps the most striking fact brought out by study of the tables and diagrams representing compartment

TABLE 10. TOTAL-CUBIC-FOOT VOLUMES, BY COMPARTMENTS

Compartment no.	Volume in total cubic feet					
	Removed in cutting		After cutting		Twenty years after cutting	
	Per acre	Total	Per acre	Total	Per acre	Total
1	.....	.....	144.9	4,094.8	599.1	10,286.9
2	329.3	10,408.3	1,856.0	58,663.8	2,228.9	81,578.3
3	.....	.....	267.0	3,363.0	806.5	10,162.0
4	.....	.....	1,080.0	14,360.0	1,812.7	24,109.0
5	390.0	4,680.0	1,292.0	15,504.0	1,847.2	22,166.4
6	265.9	7,585.3	1,291.0	37,343.9	1,749.2	50,552.6
7	534.8	5,348.0	110.0	1,100.0	813.2	8,132.0
8	452.3	5,383.1	1,991.0	23,703.1	2,711.3	32,264.3
9	366.6	14,777.3	1,420.0	57,264.7	2,245.6	90,500.9
10	378.5	12,187.8	876.6	28,224.6	1,998.2	64,342.7
11	404.4	7,724.2	1,402.5	26,788.4	1,963.0	38,497.6
12	372.2	18,463.7	724.0	35,933.0	1,439.6	71,508.8
13	967.1	11,895.3	731.3	8,996.2	1,309.8	16,110.6
Total	.....	98,453.0	.....	315,339.5	.....	520,212.1

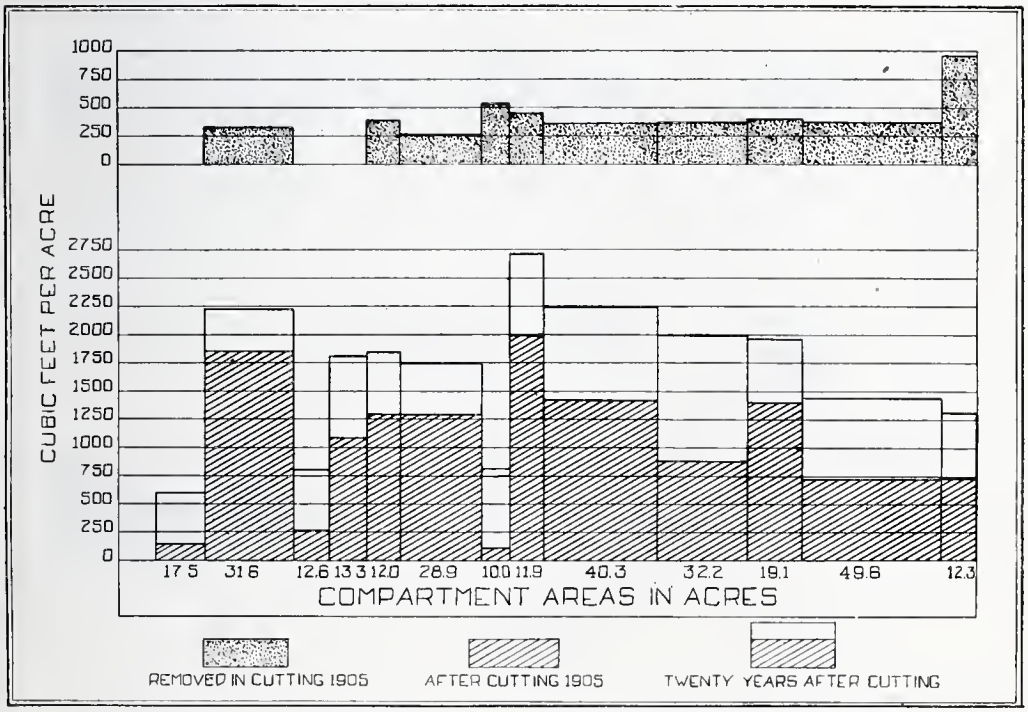

FIGURE 8. VOLUME GROWTH IN TOTAL CUBIC FEET, BY COMPARTMENTS

TABLE 11. BOARD-FOOT VOLUMES, BY COMPARTMENTS

Compartment no.	Volume in board feet					
	Removed in cutting		After cutting		Twenty years after cutting	
	Per acre	Total	Per acre	Total	Per acre	Total
1	.....	.....	.....	.....	116	2,030
2	462.7	14,623.6	3,904	123,377.6	7,207	227,741
3	.....	.....	.....	.....	.....	.....
4	.....	.....	864	11,491.2	2,203	29,300
5	.....	.....	1,090	13,080.0	2,486	29,832
6	253.5	7,326.4	836	24,156.3	1,724	49,768
7	.....	.....	.....	.....	.....	.....
8	139.2	1,656.6	2,760	32,816.3	6,792	80,822
9	98.1	3,957.2	857	34,542.8	2,577	103,746
10	443.8	14,291.2	1,218	39,212.8	3,404	109,500
11	253.9	4,850.3	1,477	28,218.0	3,948	79,490
12	101.4	5,031.6	860	42,656.8	1,709	84,760
13	1,082.0	13,309.8	1,678	20,639.0	4,926	60,600
Total	.....	65,046.7	.....	370,190.8	.....	857,589

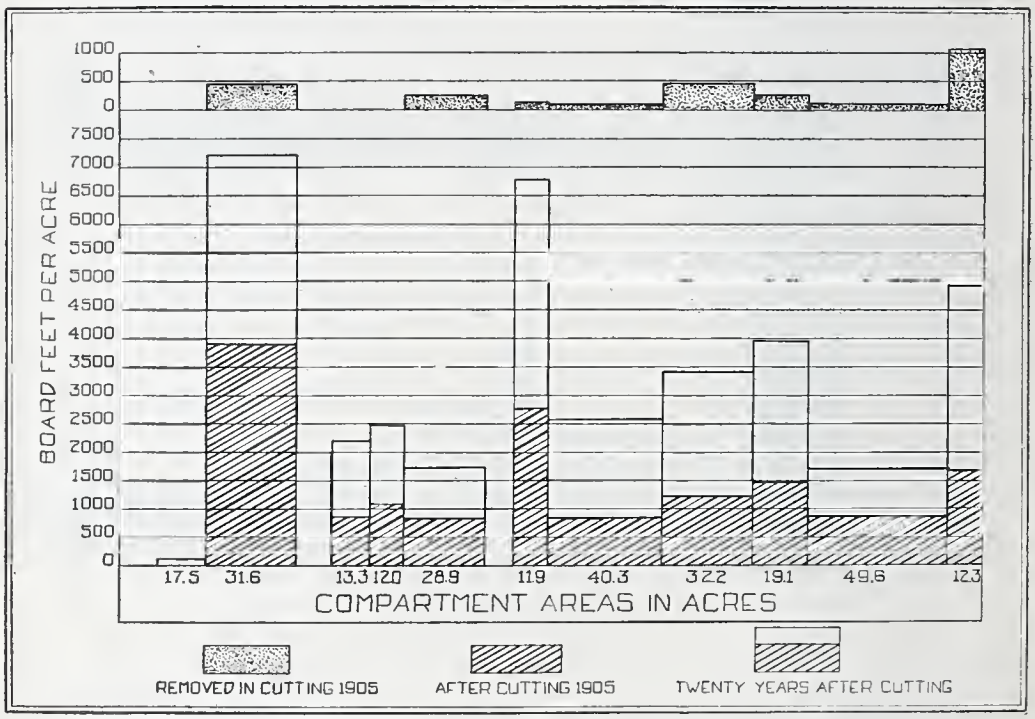

FIGURE 9. VOLUME GROWTH IN BOARD FEET, BY COMPARTMENTS

TABLE 12. ADDITIONAL-CUBIC-FOOT VOLUMES, BY COMPARTMENTS

Compartment no.	Volume in additional cubic feet					
	Removed in cutting		After cutting		Twenty years after cutting	
	Per acre	Total	Per acre	Total	Per acre	Total
1	.....	.....	177.4	3,104.8	549.2	9,776.6
2	233.8	8,390.2	929.5	29,374.5	1,195.9	37,793.0
3	.....	.....	267.5	3,370.5	806.2	10,158.1
4	.....	.....	853.2	11,347.5	1,187.8	15,797.7
5	390.0	4,680.0	1,144.8	13,377.6	1,293.4	15,520.8
6	229.3	6,627.6	1,107.3	32,051.9	1,263.4	36,510.2
7	534.8	5,348.0	110.0	1,100.0	831.2	8,312.0
8	395.5	4,707.5	1,392.0	16,574.7	1,230.9	14,648.8
9	341.1	13,749.0	1,292.4	52,085.0	1,667.3	67,192.9
10	227.5	7,326.7	598.5	19,172.9	1,241.0	39,963.1
11	339.2	6,480.3	1,066.1	20,364.6	1,074.7	20,527.8
12	347.8	17,251.5	487.3	24,172.3	977.8	48,499.8
13	661.9	8,141.3	446.4	5,490.7	635.6	7,820.3
Total	.....	82,702.1	.....	231,587.0	.....	332,521.1

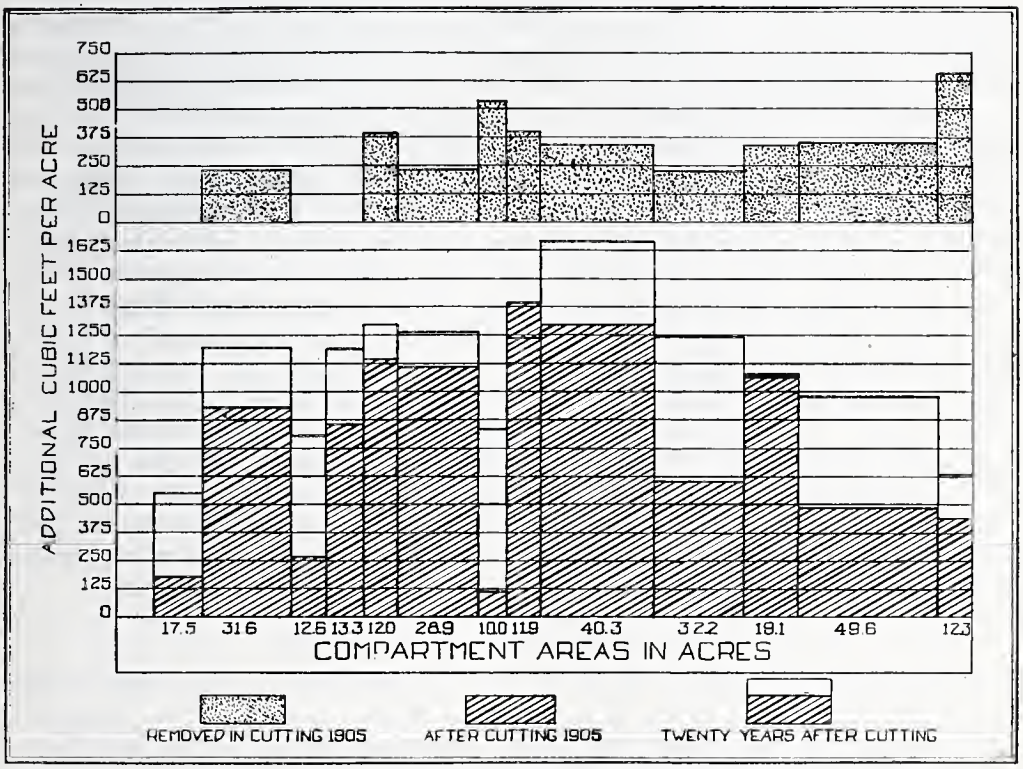

FIGURE 10. VOLUME GROWTH IN ADDITIONAL CUBIC FEET, BY COMPARTMENTS

TABLE 13. AVERAGE PERIODIC ANNUAL INCREMENT PER ACRE BY COMPARTMENTS, 1905 TO 1925*

Compartment no.	Periodic annual increment per acre		
	Cubic feet	Board feet	Additional cubic feet
1	22.7	5.8	18.5
2	18.6	165.1	13.3
3	26.9	.....	26.9
4	36.6	66.9	16.7
5	32.7	69.8	7.4
6	22.9	44.4	7.8
7	35.1	.....	36.0
8	36.0	201.6	8.0
9	41.2	86.0	18.7
10	56.1	109.3	32.1
11	46.0	123.5	0.4
12	35.7	42.4	24.5
13	28.9	162.4	9.4
Weighted average for forest	35.2	83.6	17.3

* On compartments 1 to 6 inclusive, all stands were of the chestnut oak type. On compartments 7, 10, 12, and 13, all stands were of the white oak type. On compartments 8, 9, and 11, the white oak type predominated but hardwood swamp stands were present.

volumes and growth. Compartments 1 to 6 inclusive are of the chestnut oak type; on the seven other compartments the white oak type predominates, but on some of them small areas of the swamp hardwood type occur also. It is apparent from an examination of the tables and diagrams that the periodic annual increment was greatest on compartments 7 to 13. The actual average periodic annual increment in total cubic feet in the compartments of the chestnut oak type was 28.2 cubic feet, as compared with 39.7 cubic feet per acre per year on the others. The periodic annual increment of the chestnut oak type was 71.7 board feet, while that of the white oak type was 91.6 board feet. The difference in growth would normally be more striking in board feet than in cubic feet. That it was not is due almost wholly to the unusual board-foot increment of compartment 2, which, as is shown in table 9, contained plots 39, 36, 32, and 31. The board-foot increments for these plots exceeded those of the other plots of this type. The reasons for their high growth rates, as has been shown in the discussion under "Volume growth of sample plots," are the presence of a large proportion of red oak and the fact that the plots were of the age when periodic annual increment in board feet is greatest because many trees for which a board-foot volume could not be computed at the beginning of the growing period had attained a board-foot volume at its close.

SILVICAL EFFECTS OF CUTTINGS

The aim of the cuttings made on the sample plots in 1905 was to put them into the best possible condition for future growth. The character of the cutting on any particular plot was dependent upon the age and the condition of that plot. The author has classified the cuttings, for the purpose of the present discussion, on the basis of the character and volume

of the material removed and the volume which remained after the cutting as shown on the original tally sheet. Such classification is shown in table 1 (page 8). The classification does not conform to that of the United States Forest Service, made at the time when the plots were established, which recognized only "improvement thinnings" and "reproduction cuttings." On young plots the cuttings naturally assumed the forms of cleanings and liberation cuttings, on middle-aged plots they were improvement cuttings which frequently were in effect thinnings, and on mature and over-mature plots they fell into the categories of improvement cuttings and reproduction cuttings.[7]

The general character of the cutting for each forest type is indicated by the average percentages of the various species removed in cutting and remaining after cutting. These percentages are shown for number of trees, total-cubic-foot volume, board-foot volume, and additional-cubic-foot volume, by forest types, in table 14. In addition the table shows the percentages of the various species present twenty years after the cutting. The table was prepared by summarizing for each forest type, by species, the values of the individual plots (computed for this study as described under "Computation of volumes," pages 14 to 18) and converting into percentages the total values thus obtained. This table is the foundation for any discussion of the silvical effects of cuttings, for it reveals not only what was done and the conditions thus established, but also the changes which occurred during the succeeding twenty-years growth period.

The characteristic differences between the types as régards percentages of the various species present, both in number of trees and in volume, are shown by comparisons of the amounts removed, those remaining after cutting, and those present in 1925. For the white oak type the species white oak is truly predominant. It exceeds all other species, not only in number of trees and cubic volume remaining after cutting, but also in the amount removed in cutting. Furthermore, it retains its place as the most abundant species thruout the twenty-years growth period. For the chestnut oak type the species chestnut oak is truly predominant. It exceeds all other species, both in number of trees and in cubic volume removed and remaining after cutting. Thruout the twenty-years growth period it retains its place as the most abundant species numerically, tho red oak, due to a more rapid growth rate, exceeds it in volume at the end of the period. An examination of table 14 shows further that black oak is the principal associate in the white oak type, while red oak is the principal associate in the chestnut oak type.

The management plan recommended that hickory be most favored as the most valuable hardwood in the forest.[8] It is shown in table 14 that very little hickory was removed in cutting. That it was not abundant at the time when the cuttings were made is evidenced by the fact that, tho little was removed, it constituted only 7.7 per cent of the total-cubic-foot volume of the white oak type and 8.0 per cent of that of the chestnut oak type after cutting. During the twenty-years growth period the cubic-foot-volume percentages of hickory were reduced to 4.6 per cent

[7] All technical terms are used as defined in the forest terminology adopted by the Society of American Foresters and published in the Journal of Forestry, vol. 15, no. 1, January, 1917.

[8] The working plan (Peters, 1905) states: "At the outset it is well to emphasize the recommendation that hickory, the most valuable hardwood in the forest, should be the most favored."

TABLE 14. PERCENTAGES OF VARIOUS SPECIES IN MIXTURE, BY FOREST TYPES
(Based on 16,767 trees)

Species	Removed in cutting				After cutting				Twenty years after cutting			
	Number of trees	Cubic feet	Board feet	Additional cubic feet	Number of trees	Cubic feet	Board feet	Additional cubic feet	Number of trees	Cubic feet	Board feet	Additional cubic feet
						White oak type						
White oak	25.3	28.3	48.8	25.4	19.6	30.5	25.0	23.9	17.8	32.4	33.2	27.5
Chestnut oak	14.4	11.1	9.5	11.3	19.1	14.2	8.2	16.5	13.1	16.1	12.4	15.7
Black oak	11.5	21.7	35.9	19.0	14.0	29.8	42.4	28.2	10.3	28.4	32.1	26.3
Red oak	1.4	1.9	1.9	1.5	3.6	9.7	17.3	7.9	3.0	10.7	17.7	7.1
Hickories	7.6	4.5	.....	5.3	14.4	7.7	....	11.7	10.4	4.6	.....	8.7
Other species	39.8	32.5	3.9	37.5	29.3	8.1	7.1	11.8	45.4	7.8	4.6	14.7
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
						Chestnut oak type						
White oak	10.7	8.6	10.9	8.5	10.6	13.3	17.3	10.6	4.2	10.8	16.8	8.9
Chestnut oak	24.3	27.0	29.0	24.2	30.1	28.6	28.5	28.7	21.9	26.4	34.8	21.3
Black oak	5.2	10.6	34.7	6.2	1.9	4.8	10.2	2.5	0.6	3.8	5.0	3.4
Red oak	11.4	17.9	25.4	16.4	14.3	27.5	44.0	19.3	14.8	31.9	43.4	20.1
Hickories	9.7	6.7	.....	8.3	14.6	8.0	.....	12.1	8.7	4.5	.....	7.7
Other species	38.7	29.2	.....	36.4	28.5	17.8	.....	26.8	49.8	22.6	.....	38.6
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
						Hardwood swamp type						
Swamp white oak	34.1	50.1	.....	50.1	34.6	56.7	100.0	36.5	11.8	45.4	100.0	26.2
Red maple	38.1	33.8	.....	33.8	37.7	29.1	.....	42.7	41.9	45.7	.....	61.7
Elm	8.9	7.0	.....	7.0	3.3	3.1	.....	4.5	0.7	.....	.....	.....
Other species	18.9	9.1	.....	9.1	24.4	11.1	.....	16.3	45.6	8.9	.....	12.1
	100.0	100.0	.....	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

and 4.5 per cent, respectively. This seems to have been due largely to the killing of the trees by the hickory bark beetle.[9]

For the hardwood swamp type, red maple and swamp white oak are predominant. In 1905 the greater percentage of volume was swamp white oak, with red maple exceeding it slightly in number of trees. After twenty years growth red maple, due to a higher growth rate, equaled swamp white oak in volume, while it greatly exceeded that species in number of trees because of its superior ability to reproduce.

It is shown in table 14 that, in each of the three types, the cuttings removed principally the kinds of trees which were grouped together and designated as "Other species." Of the trees removed in the white oak, chestnut oak, and swamp hardwood types, 39.8 per cent, 38.7 per cent, and 18.9 per cent, respectively, were in this class. The principal species taken out were red maple, aspen, black birch, ironwood, shadbush, dogwood, elm, witch-hazel, and hemlock. After the cuttings, 29.3 per cent, 28.5 per cent, and 24.4 per cent, respectively, of the trees remaining were in the class "Other species." These were mostly of the more desirable species — hard maple, white ash, black cherry, basswood, and pine. During the twenty years of growth the tree-number percentages of "Other species" had increased to 45.4 per cent, 49.8 per cent, and 45.6 per cent, respectively. It is important to note that decided increases in tree-number percentages in all three types were coincident with slight losses in percentage of cubic-foot volume in the white oak and swamp hardwood types, and with only a slight gain in percentage of cubic-foot volume in the chestnut oak type. This proves conclusively that these increases in tree-number percentages are due almost wholly to the disproportionate addition of young growth of the "Other species" group which was under the one-inch diameter limit in 1905 but which grew into the one-, two-, and three-inch diameter classes during the twenty-years period, rather than to a loss of trees of the species classified separately. Increases in tree-number percentages of the "Other species" group due to the loss of trees of species classified separately, would necessarily be accompanied by substantial gains in cubic-foot-volume percentages.

INTERMEDIATE CUTTINGS

Cleanings

Of the forty-three sample plots established, but two were in young stands requiring cleanings in 1905. Of these two, the first, plot 9, was ten-years-old seedling and sprout reproduction on cut-over land; the other, plot 13, was seedling hardwood (average age eight years) coming in on abandoned sod land. Plot 13 was cleared in 1910 and planted to pine, so that no 1925 remeasurement was possible.

Plot 9, white oak type (figure 11), was well stocked with desirable young growth. The cleaning (as shown in table 15) removed all but three of the trees three inches and more in diameter breast-high. The trees removed were principally chestnut sprouts which, because of their more rapid growth,

[9] The following notes were written into a copy of the plan by Colonel Rogers: "December 1914. Hickory: Many hickory trees are dead all over this woods — from hickory bark beetle." "Dec. 1915. During the summer of 1915 many dead hickories observed. These were cut out in winter of 1915–16. Summer of 1916 considerably less dead trees observed."

FIGURE 11. WHITE OAK TYPE. THIRTY-YEARS-OLD EVEN-AGED STAND IN WHICH CLEANING WAS MADE AT THE AGE OF TEN YEARS (PLOT 9)

had overtopped desirable young growth. All trees in the group "Other species" which threatened to overtop more desirable kinds were taken out. Those in this group which remained either were of desirable species or were not competing successfully for space. As a result of the cutting, a uniform young growth composed of trees from one to three inches in

TABLE 15. COMPARISON OF 1905 AND 1925 TALLIES ON PLOT 9

(Area, one-quarter acre)

Species	1905 Removed in cutting									1905 After cutting				1925 After twenty years growth								
	1"	2"	3"	4"	5"	6"	7"	8"	Total	1"	2"	3"	Total	1"	2"	3"	4"	5"	6"	7"	8"	Total
	Number of trees																					
White oak	..	4	1	..	..	..	..	..	5	18	18	2	38	3	9	3	8	10	7	4	2	46
Black oak	..	..	..	..	..	..	..	..	.....	4	3	..	7	4	8	4	9	4	6	3	2	40
Red oak	..	..	..	..	..	..	..	..	.....	2	..	..	2	..	2	..	2	1	..	..	..	5
Chestnut oak	..	2	1	1	..	..	..	..	4	1	2	1	4	..	4	2	6	1	2	1	1	17
Hickory	..	..	..	..	..	..	..	..	.....	19	5	..	24	8	8	12	2	1	..	..	..	31
Chestnut	..	4	12	1	..	..	..	..	17	4	4	..	8	..	..	..	..	..	..	..	..	.....
Maple (hard)	..	..	..	..	..	..	..	..	.....	....	..	..	.....	14	11	11	3	..	1	..	..	40
Other species	17	3	1	..	1	..	..	1	23	61	5	..	66	7	1	5	3	..	..	1	..	17
Total	17	13	15	2	1	..	..	1	49	109	37	3	149	36	43	37	33	17	16	9	5	196

diameter was established. The tally for 1925 which classified the trees into three crown classes (table 16) shows that of the 81 stems four inches and more in diameter, 91.4 per cent were in the dominant crown class; and that of the 115 stems less than four inches in diameter, only 16.5 per cent were dominant. Hard maple was not tallied separately in 1905, but was segregated from other miscellaneous species in 1925 in order that its relative position in the stand might be apparent. The classification

TABLE 16. TALLY OF PLOT 9 SHOWING CROWN CLASS DISTRIBUTION BY SPECIES AND DIAMETER, 1925*

(Area, one-quarter acre)

Diameter breast-high (inches)	White oak			Black oak			Red oak			Chestnut oak			Hickory			Maple (hard)			Other species		
	D	I	O	D	I	O	D	I	O	D	I	O	D	I	O	D	I	O	D	I	O
1	...	...	3	...	...	4	...	...	...	...	...	...	...	...	8	...	...	14	...	...	7
2	...	3	6	2	...	6	1	...	1	...	2	2	...	3	5	...	1	10	...	...	1
3	...	1	2	4	...	...	...	...	...	2	...	...	6	1	5	4	4	3	...	4	...
4	7	1	...	8	1	...	2	...	...	6	...	...	2	...	...	2	1	...	...	4	...
5	10	...	...	4	...	...	1	...	...	1	...	...	1	...	...	...	...	...	...	...	...
6	7	...	...	6	...	...	...	...	...	2	...	...	...	...	...	1	...	...	...	...	...
7	4	...	...	3	...	...	...	...	...	1	...	...	...	...	...	...	...	...	1	...	...
8	2	...	...	2	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...
Total	30	5	11	29	1	10	4	...	1	13	2	2	9	4	18	7	6	27	1	8	8

* D, dominant; I, intermediate; O, overtopped.

showed that only seven of the forty maples present were in the dominant crown class. Hard maple was present on most of the plots, but it nearly always occupied a subordinate position in the crown cover. (This is discussed under " Seedling reproduction," page 42.)

Liberation cuttings

The treatments given plots 12 and 18 were in the nature of liberation cuttings. The results obtained on these two plots were almost identical with the result on plot 9, discussed above under " Cleanings." After the cuttings there remained well-stocked, even-aged, eight- to ten-years-old sapling stands. The chief difference between these liberation cuttings and the cleanings described above was that the liberation cuttings removed trees older and larger than those left, while in the cleanings the trees removed were of the same age as those left. The liberation cuttings removed mostly trees from three to eight inches in diameter which remained either as " left-overs " from a previous stand or as advance growth reproduction, and which, in either case, were older than the new growth. That plot 9 exceeded plots 12 and 18 in cubic-volume production during the twenty-years period is shown in table 5. The tally sheets seem to indicate that in the case of plot 12, where the discrepancy is not great, it is due to a less favorable distribution of the dominant stems. In the case of plot 18 the average total height of the dominant trees is five feet less than on plot 9, indicating a lower site quality, and the crown cover is slightly less complete. The lower volume growth must therefore be due largely to lower site quality, tho lower density is a contributory factor.

Improvement cuttings

Improvement cuttings were made on twenty-three of the forty-three sample plots. The aim of these cuttings was to bring the stand into better condition and composition for silvicultural management by the removal of trees of undesirable form, condition, and species. In a number of the younger stands improvement cuttings functioned as thinnings, for they resulted in increased growth rate of the trees left. In the older stands they frequently opened up the crown canopy to such an extent that abundant natural reproduction came in.

Plate I

PLOT 8, WHITE OAK TYPE. IMPROVEMENT CUTTING

(See table 5 for volumes removed and remaining after cutting in 1905, and volume present in 1925 after twenty years of growth)

1, A fairly dense forty-years-old stand marked for a moderate improvement cutting which will remove a large number of crooked and defective individuals of desirable species. (Photograph by U. S. Forest Service)

2, The same stand after 1905 cutting. About half of this plot is dry ridge on which chestnut oak predominates. A large amount of small bushy reproduction is present. Number of 1- and 2-inch trees per acre, 120. (Photograph by U. S. Forest Service)

3, The same stand in 1925 after twenty years growth. Reproduction is abundant except on the dry ridge. In order of their numerical importance the species of the reproduction are chestnut oak, hard maple, hickory, white ash, and black oak. Number of 1- and 2-inch trees per acre, 278

Plate II

PLOT 10, WHITE OAK TYPE. IMPROVEMENT CUTTING

(See table 5 for volumes removed and remaining after cutting in 1905, and volume present in 1925 after twenty years growth)

1, A thirty-five-years-old stand, containing scattered remnants of an early stand, marked for an improvement cutting which will remove crooked and defective individuals in all crown classes. (Photograph by U. S. Forest Service)

2, The same stand after 1905 cutting. The growing stock is greatly reduced. The remaining trees are thrifty, well formed, and free to grow. The stand at maturity should yield timber of exceptional quality. (Photograph by U. S. Forest Service)

3, The same stand in 1925 after twenty years growth. Due to its understocked condition the cubic-foot and board-foot average annual increments over the twenty-years period have been only 39.25 cubic feet and 115.7 board feet, respectively, but the rate of diameter increase of the trees has been high. Chestnut oak and white oak have been reproduced abundantly

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Plate III

PLOT 5, HARDWOOD SWAMP TYPE. IMPROVEMENT CUTTING

(See table 7 for volumes removed and remaining after cutting in 1905, and volume present in 1925 after twenty years growth)

1, A forty-five-years-old swamp hardwood stand, predominantly red maple. This may be contrasted with plot 17 (Plate IV). The lack of understory is to be especially noted. The stand is to receive a light improvement cutting which will remove crooked and defective trees in all crown classes. (Photograph by U. S. Forest Service)

2, The same stand after 1905 cutting. It is now well stocked with thrifty dominant trees. (Photograph by U. S. Forest Service)

3, The same stand in 1925 after twenty years growth. The periodic annual increment for the twenty-years period has been 59.6 cubic feet. This is a very satisfactory growth rate for a swamp type

Plate IV

PLOT 17, HARDWOOD SWAMP TYPE. IMPROVEMENT CUTTING

(See table 7 for volumes removed and remaining after cutting in 1905, and volume present in 1925 after twenty years growth)

1, A swamp hardwood stand, predominantly swamp white oak. Many dead and dying trees of poor form in the understory are to be removed in the improvement cutting. There is to be no cutting in the upper crown classes. (Photograph by U. S. Forest Service)

2, The same stand after 1905 cutting. The lack of advance-growth reproduction is to be noted. With a predominance of heavy-crowned swamp white oaks in the dominant stand, reproduction of this species is expected. Number of 1-inch trees per acre, 48. (Photograph by U. S. Forest Service)

3, The same stand in 1925 after twenty years growth. No swamp white oak seedlings have appeared. Dominant red maples should now be cut, to give ash reproduction increased light. The 44 dominant swamp white oaks in the 7- to 10-inch diameter classes may be left. Number of 1-inch trees per acre, 412 — white ash, 276; red maple, 88; birch, 32; elm, 16. Dense reproduction of white ash has sprung up

Plate V

PLOT 20, WHITE OAK TYPE. REPRODUCTION CUTTING

(See table 5 for volumes removed and remaining after cutting in 1905, and volume present in 1925 after twenty years growth)

1, Seedling advance-growth white-pine reproduction, to be released by removal of a part of the dominant pine and hardwood stand. Blazes are shown in hardwoods marked for cutting which will take 57 per cent of the total number of trees, 57 per cent of the total-cubic-foot volume, and 44 per cent of the board-foot volume. (Photograph by U. S. Forest Service)

2, The same in 1905 immediately after cutting, showing advance-growth pine and hardwood released. Two well-formed, heavy-crowned pines (not seen in the photograph) are left for natural seeding to supplement advance growth. Number of pines per acre in the 1- to 6-inch diameter classes, 48. (Photograph by U. S. Forest Service)

3, The same in 1925 after twenty years growth. The young pine stand is well established. The remaining trees of the original stand should be cut. Number of pines per acre in the 1- to 6-inch diameter classes, 890

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Plate VI

PLOT 7, WHITE OAK TYPE. REPRODUCTION CUTTING

(See table 5 for volumes removed and remaining after cutting in 1905, and volume present in 1925 after twenty years growth)

1, A sixty-five-years-old white oak stand before reproduction cutting in 1905. The large amount of hemlock in the understory is to be noted. (Photograph by U. S. Forest Service)

2, The same stand after 1905 cutting, which removed 195 trees (390 per acre), of which 90 were hemlock. In addition to the hemlock, the oldest and poorest trees in the dominant crown class were taken out. Number of 1- and 2-inch trees per acre, 30. (Photograph by U. S. Forest Service)

In 1925 abundant seedling reproduction under 1 inch in diameter breast-high was present. Number of 1- and 2-inch trees per acre, 174 — hard maple, 65; "other species," 27; chestnut oak, 17; white oak, 16; hickory, 15; white ash, 15; black oak, 12; red oak, 5; pine, 2

Plots 8 and 10 are representative of younger stands of the white oak type in which improvement cuttings were made. They were forty years old and thirty-five years old, respectively, in 1905. Plot 8 (Plate I) was irregular in density and site quality. The lower part was well stocked with white oak and black oak. The drier ridge in the center of the plot was less dense. Chestnut oak was the predominating species in the drier part. The improvement cutting in this plot removed 178 crooked and defective trees per acre, of which not more than 20 affected the dominant stand. This improvement cutting did not appreciably open up the crown cover. Plot 10 (Plate II) was relatively uniform in density. White oak and black oak were the predominating species. The improvement cutting removed 250 trees per acre, of which at least 60 were dominant. It left a fairly uniform, relatively open, crown cover in which many dominants were free to grow. It had the effect of a thinning. During the twenty-years growth period following the cutting, the diameter increases of these dominants were exceptional. The average diameter increase of all trees six inches and more in 1905 was 12 per cent greater on plot 10 than on plot 8. The total per-acre cubic-foot increment over the twenty-years period was 9.5 per cent greater on plot 10 than on plot 8, altho the number of trees present was 24.4 per cent less.

Improvement cuttings in the chestnut oak type were confined almost wholly to the removal of trees in the lower crown classes.

Plots 5, 17, and 43 represent improvement cuttings in the swamp hardwood type. On plot 5 (Plate III) the cutting removed crooked and defective trees in all crown classes. On plot 17 (Plate IV) only dead and dying trees in the overtopped crown class were taken out. On both plots the volume of red maple remaining after the cutting in 1905 was only about 50 per cent as great as the swamp-white-oak volume. But after twenty years growth the red-maple volume exceeded the swamp-white-oak volume on plot 17 by 74 per cent and on plot 5 by 26 per cent.

REPRODUCTION CUTTINGS

General

The Crumwold Forest sample plots offer opportunities for detailed studies of the effects of cuttings on reproduction. Such studies are contemplated. The results herein presented were observed in connection with the study of volume growth. They are chiefly statements of observed facts the causes of which require careful investigation.

On eight of the sample plots (three of the white oak type, three of the chestnut oak type, and two of the hardwood swamp type), the cuttings were made in mature stands for the purpose of bringing about natural regeneration. On three additional chestnut-oak plots — 32, 41, and 42 — cuttings had been made just previous to the date of establishment, so that when established these plots were in the reproduction stage.

The means to be used in reproducing the various species and forest types were set forth in the original plan (Peters, 1905) as follows:

> There are four species which the working plan will seek to reproduce almost entirely by seed; these are white oak, swamp white oak, white ash, and white pine.
>
> Of particular importance over certain areas of the tract is the prolific reproduction of seedling white oak, especially noticeable here for the reason that in many localities

the reproduction of white oak from seed is nearly wanting. Though it is a relatively poor seed producer, this shortcoming is greatly offset by a relatively high germinating percentage of the seed and by the favorable conditions for germination. The acorns of white oak are extremely edible, and hence are much sought by rodents. Here, however, these seed-destroying factors, with the exception of some few squirrels, which are apparently satisfied by chestnuts, are almost wanting, and this fact, together with the total absence of fire over white oak areas, accounts unquestionably for the prolific regeneration of the species. The most even regeneration occurs on the best situations where the forest cover is open or considerably broken, and where the leaf litter is fresh and sufficiently deep to cover the acorns. Seeds are borne every year or at least every second year, ripening in late September, when they fall and soon germinate. The working plan will seek to reproduce white oak by self-sown seed from seed trees.

Swamp white oak, like white oak, is also not a prolific seeder. The reproduction of the tree is extremely poor, and since there are practically no seed-destroying factors, it is believed, though not entirely proved, that this lack of reproduction is due chiefly to frost killing. The seeds germinate soon after falling, in early October, and since frosts occur earlier and are more severe in swamps than on higher land and in drier situations, it is probable that the young shoots are killed by frost before they are sufficiently hardy to resist. The fact that white oak, the seed of which germinates in the fall, is not seriously frost-touched is due no doubt to its occurring on relatively drier situations. Compared with the reproduction of the black oaks, that of the white oaks is at a disadvantage in that their seed germinates in the fall and thus the young plants are endangered by frost, whereas the seed of the black oaks lies over winter and germinates the following spring. Swamp white oak reproduces best under an open forest cover where the soil is only fairly moist.

White ash is a very prolific seeder, and produces seed abundantly about every second year. The fruit ripens in October, falling and germinating the next spring. It is light and winged, and is therefore largely disseminated by the wind, a fact to be borne in mind in leaving seed trees. The reproduction of white ash is more or less prolific in spite of its low germinating percentage, and the reason that in the older stands it is not more numerous is due primarily to its great intolerance of shade after it passes the small seedling stage. The most even regeneration occurs on scant leaf litter under a broken forest cover, though excellent regeneration frequently occurs under a fairly dense stand. The working plan will seek to reproduce white ash by self-sown seed from seed trees.

White pine produces seed in abundance about every three to five years. The seeds, which have a high germinating percentage, mature and fall in September of the second year from flowering, and germinate the following spring. The most successful regeneration occurs near seed trees in the white oak and old field types where the leaf litter is scant and the forest cover broken. The young seedlings require some shade the first few years, after which they do best in full sunlight. White pine seeds are winged and light, and are disseminated chiefly by wind. An excellent illustration of this is the abundant regeneration in compartment 13, the seed, for the most part, having been blown from trees to the north and northwest in the adjoining tract. As with white oak, swamp white oak, and white ash, the working plan will seek to reproduce white pine in the forest by self-sown seed from seed trees.

Sprout reproduction

With the exception of white oak, swamp white oak, and white ash, all the other hardwoods will be reproduced chiefly from sprouts. It is a well-known fact that the sprouting capacity and the sprouting vigor of different hardwoods vary not only with respect to each other, but especially with respect to the size or age of individual trees of the same species. By *sprouting capacity* is meant the power to produce sprouts from the stumps of cut trees; by *sprouting vigor*, the thriftiness, usually expressed in height, of the sprout itself. These factors, it will be shown, have a most important bearing on forest management, and a thorough knowledge as to their interrelations is certainly essential to the successful treatment of the various species to be relied on for sprout reproduction.

In order to learn and compare the sprouting capacity of the different hardwoods, measurements were taken of 666 stumps, from which was determined the percentage of these stumps that had sprouted. This is shown in the following table:

TABLE VI. SPROUTING CAPACITY OF VARIOUS HARDWOODS EXPRESSED IN THE PERCENTAGE OF STUMPS THAT HAD SPROUTED

Stump diameter outside bark (inches)	Chestnut	Chestnut oak	White ash	Red oak	Black and scarlet oak	Hickories	White oak	White elm	Red maple	Swamp white oak
	Per cent of stumps which had sprouted									
1– 4	100	100	100	100	100	100	100	100	100	100
5– 8	100	100	100	100	100	62	100	65	95	82
9–12	100	100	83	82	62	67	67	36	33	33
13–16	100	87	80	68	75	56	38	42	25	.....
17–20	100	78	.....	79	50	75	15	22	.....	.....
Over 20	89	50	.....	50	.....	.....	7	.....	.....	.....
Number of stumps examined	43	65	52	83	54	59	96	87	75	52

The important facts brought out in this table are that—

1. Chestnut, chestnut oak, white ash, red, black, and scarlet oak, and the hickories, retain the power to sprout scarcely undiminished for a comparatively long period; white oak, white elm, red maple, and swamp white oak lose this power at a comparatively early period.

2. All the species, with the possible exception of white elm, can be relied on to sprout almost unfailingly up to eight inches in diameter on the stump.

3. After reaching eight inches, white oak, white elm, red maple, and swamp white oak show a marked decline; the three latter can scarcely be relied on to sprout at nine inches, and the white oak, failing materially at nine inches, can scarcely be relied on at thirteen inches; and white elm will utterly fail to sprout at twenty inches, red maple at seventeen inches, and swamp white oak at thirteen inches.

4. Chestnut has the greatest sprouting capacity of any of the species, and will sprout unfailingly up to at least twenty inches in diameter.

The practical value of this table is unquestioned, for it clearly shows that if white elm, red maple, and swamp white oak are reproduced by sprouts and managed on any other than a short rotation they must fail; and that white oak likewise would scarcely succeed. By *rotation* is meant the period represented by the age of a forest at the time when it is finally cut over.

One of the most striking features of Table VI is the regularity of the figures, which is particularly so with respect to chestnut oak and white oak. It should be stated that these figures represent the actual averages of field measurements, neither made regular nor rounded off by curves. To this actual regularity, therefore, all the more value is attached. Obviously the hickory figures are extremely irregular, and this is due to the fact that all of the hickories, which differ from each other as to their sprouting capacity, have been averaged together. The reason for including them is merely to show that the hickories have a high sprouting capacity.

In order to learn the sprouting vigor of the different hardwoods, measurements were taken of 461 stumps, from which was determined the height of sprouts one year old. This is shown below.

TABLE VII. COMPARATIVE SPROUTING VIGOR OF VARIOUS HARDWOODS EXPRESSED IN THE HEIGHT OF A SPROUT ONE YEAR OLD

Species	Height of one-year-old sprouts (feet)	Number of stumps examined
Chestnut	6.7	42
White ash	4.3	50
Chestnut oak	3.8	59
Red maple	3.7	54
Red oak	3.3	65
Black and scarlet oak	2.8	49
Hickory	2.5	42
White elm	2.4	39
Swamp white oak	2.4	20
White oak	2.2	41
		461

The important facts brought out in this table are that nearly all the species which the working plan will seek to regenerate by sprouts are exceedingly vigorous sprouters, and that white oak is not a vigorous sprouter.

The chestnut, oaks, and hickories usually sprout from what is known as the root collar, or the base of the tree, and never from the top of the stump, but in cases where stumps have been cut exceptionally high there is a tendency to sprout near the top. Chestnut oak possesses an additional characteristic of sprouting from its roots, by what are known as *root suckers*. This occurs, however, only where the roots are near the surface of the ground, and when they have been injured. White ash usually sprouts near the top of the stump; red maple, almost equally from the root collar and near the top; and white elm entirely from the top. The most vigorous sprouts originate at the root collar, where they derive most nourishment from the roots, establish root systems of their own, and are the least liable to be reached by decay from the old stump, all of which has a particular bearing on the height of cutting the stumps.

It is generally conceded, especially where sprout reproduction is desired, that cutting low stumps produces the very best results, for the reason just given above. Also, the stumps should have a slanting surface, in order that as little water as possible will collect thereon and so induce decay. Of utmost importance is that the cutting should be done in the winter or early spring, in order that the young sprouts may have sufficient time through a long growing season to become hardy before the autumnal frosts.

Reproduction cutting

This has as its object essentially the renewal of the stand. It operates in two ways—by clean cutting with natural reproduction or planting or sowing, or by leaving seed trees to eventually seed the area to be reproduced. There are many combinations possible from these methods, and it will suffice here to discuss only those that are particularly applicable to this forest. However, the broad statement may be made that, owing to the generally poor quality of the soil, it is believed that sprout forests will produce the largest returns, and that seedling growth should be encouraged only on the best situations.

White oak land is best suited to the composite system of forest management, under which reproduction is secured by both sprouts and seedlings. White oak and white ash are valuable for lumber purposes and where possible should be reproduced with a view to reaching saw-log size. This can be accomplished best by reproducing them from seed. The best situations are found in this type of forest, and it is believed that white oak and white ash will do particularly well as seedlings. White pine, the most valuable lumber tree on the tract, should also be allowed to reach saw-log size. The other hardwoods should be managed as a sprout forest, of which hickory, chestnut, and red oak should be chiefly encouraged. The resulting stand will be what is technically known as a *reserve sprout forest*, or a two-storied forest in which seedlings or vigorous sprouts form the upper story, and sprouts the lower story. The stand should be thinned by ordinary improvement cuttings; the sprout forest, at the end of its rotation, should be cut clean, leaving the seed forest to remain through two or possibly three rotations of the sprout forest. It would be extremely inadvisable to manage this type as a sprout forest only, for the percentage of white oak in the type would in all probability decrease, which is highly undesirable. As has been shown, it scarcely possesses the power to sprout after reaching thirteen inches in diameter on the stump; and, moreover, its sprouting vigor is considerably less than that of the other hardwoods in this type. (See Tables VI and VII.) Therefore, it is believed that white oak if reproduced entirely by sprouts would lose its predominance in the stand. White ash, though an excellent sprouter, will not thrive in the lower story of a composite forest on account of its intolerance of shade. It is believed that white ash, grown as a seedling on white oak land, will greatly increase in number.

Chestnut-oak land is best suited to the sprout system of forest management for the following reasons:

1. Chestnut oak and red oak, the principal trees in the type, are its most vigorous sprouters, and retain their power to sprout after having reached a relatively large size. (See Tables VI and VII.)

2. Chestnut oak is fairly intolerant and, especially on poor situations, would not thrive well under the shade afforded in a composite system.

3. The sprout system is particularly suited to the production of cordwood, the product desired, and will produce the greatest yield in the shortest time.

Under this system, after having encouraged chestnut oak and red oak by improvement cuttings, the forest at maturity should be cut clean and allowed to sprout.

Swamp-white-oak land is best suited to the composite system. Swamp white oak and white ash should be reproduced by seed, the other hardwoods by sprouts. Of the latter, red maple should be chiefly encouraged, and white elm gradually gotten rid of, since it is of comparatively little value. Though swamp white oak in the present stands reproduces poorly from seed, it is believed that this can be overcome to a large extent by making the reproduction cutting very heavy. It is not a good sprouter in any respect and will do better if reproduced from seed.

Red-maple land is particularly suited to the sprout system, since its situation is normally so extremely wet that seedling reproduction is out of the question, and since maple itself is an excellent sprouter up to a certain limit. When the trees are reaching a diameter of about eight inches on the stump, the stand should be cut clean. Though practically all the red-maple land on this tract has been drained, which will certainly make seedling reproduction possible, it is nevertheless believed that red maple here is most suited to a sprout forest.

Seedling reproduction

The plan provided that white oak, swamp white oak, white ash, and white pine be reproduced by seed. The results after twenty years justify these recommendations except that practically no regeneration of swamp white oak has become established. The only plot on which swamp-white-oak reproduction was noted was plot 43. White-oak reproduction was abundant and thrifty on many plots. This species made up 17 per cent of the total reproduction in the white oak type and 7 per cent in the chestnut oak type, as shown in table 17. Practically all of this white-oak reproduction was of seedling origin.

The average percentages of the reproduction of each species, by forest types, are shown in table 17. The figures were obtained by averaging the amounts of reproduction for all sample plots of each type regardless of the kind of silvicultural treatment given in 1905. A study of this table in conjunction with individual sample-plot records forms the basis for the discussion of the effects of cuttings in bringing about reproduction.

TABLE 17. PERCENTAGES OF VARIOUS SPECIES IN REPRODUCTION, BY FOREST TYPES*

Species in reproduction	Per cent of total		
	White oak type	Chestnut oak type	Hardwood swamp type
White oak	17	7	..
Chestnut oak	10	17	..
Red oak	6	15	..
Black oak	8	7	..
Hard maple	25	20	..
White ash	8	8	55
Hickory	7	5	..
Red maple	..	..	35
Other species	19	21	10
Total	100	100	100

* Trees which must have been less than two feet high in 1905, and all tree species which originated since 1905, are included in reproduction.

White ash, another of the species to be reproduced by seed, constitutes 55 per cent of the reproduction in the hardwood swamp type. It is well

represented in the other types also. In the dominant stand white ash is nowhere abundant. There are a number of dominant white-ash trees on some of the white-oak sample plots, a few on the chestnut-oak sample plots, and two on one and one on another of the hardwood-swamp sample plots. The three hardwood-swamp sample plots on which there are no white-ash trees of seed-bearing size are those on which the reproduction is most prolific. The source of seed must be trees in the adjacent white-oak stands. There is little or no white-ash reproduction of sprout origin. Seedling white-ash is capable of enduring considerable shade in early youth. However, it requires direct sunlight for continued rapid development. It is important, therefore, that the abundant reproduction now present be released while it is yet thrifty.

White pine is the fourth species which the working plan sought to reproduce by natural seeding. It is not an important species in any of the three forest types. Most of the white pine present occurs in the white oak type. It is present in twelve of the nineteen white-oak plots but on plot 20 only is it sufficiently abundant to be considered an important component of the stand. White pine is present on only four of the eighteen chestnut-oak sample plots. On only one of these four plots, plot 38, are there dominant pines capable of producing a quantity of seed. This plot bears a very open, uneven-aged stand of trees from seven to fifteen inches in diameter, with an almost complete understory of one- to three-inch hickory, chestnut oak, white ash, and hard maple. The dense shade of this even-aged young growth prevents the establishment of white-pine seedlings. (This plot is discussed further under "Recovery from grazing," page 46.) On the hardwood swamp type there is a single suppressed one-inch pine on one plot.

It has been stated that plot 20 (Plate V) is the only sample plot on which white pine is important. The cutting in 1905 was designed to release white-pine reproduction already established, and bring about the establishment of additional pine seedlings. In this it was successful. The plot exemplifies the practicability of securing white-pine reproduction under an open crown cover of hardwood if little competition is offered by other woody undergrowth. The original plan (Peters, 1905) as quoted on page 38 states, in discussing the reproduction: "The young seedlings require some shade the first few years, after which they do best in full sunlight." The satisfactory results obtained on this plot should not be interpreted as substantiating this statement. The results indicate that young seedlings can endure a moderate amount of shade. That they do not require shade is evidenced by abundant reproduction on bare land under favorable conditions thruout the range of the species.

Hard maple, which has reproduced by seed, was not mentioned in the original working plan (Peters, 1905). In 1925 it was the most abundant species in the white oak and chestnut oak types (table 17), and must therefore be considered as an important element in the young growth. Hard-maple reproduction is present on every one of the thirty-five white-oak and chestnut-oak sample plots remeasured in 1925. It is abundant on twenty-three of these. More than one-half of the plots on which hard-maple seedlings are abundant contain no maples of seed-bearing age, and hard maple is a minor component of the dominant stand on all plots. It is most abundant in the dominant crown class in even-aged young chestnut-

oak stands on plots 32, 37, 39, 41, and 42. It is less abundant on young white-oak plots such as 9, 11, 12, and 18.

Because of its tolerance hard maple is capable of assuming a subordinate position in the stand, as the majority of its associates are relatively intolerant. In the lower crown classes or as an understory it will undoubtedly be beneficial to the site. (See discussion of plot 9 under "Cleanings," page 34, and tally of plot 9, table 15.)

The working plan (Peters, 1905) provided that all species other than those mentioned above should be reproduced by sprouts (see under "Sprout reproduction," page 38). It is apparent that by *sprouts* were meant shoots from the stumps left in cutting merchantable trees. But most of the reproduction of chestnut oak, red oak, black oak, and hickory is of seedling and seedling-sprout origin.[10] The growth characteristics of seedling sprouts resemble those of seedlings rather than those of sprouts. This leads to the conclusion that these species, as well as white oak, white ash, white pine, and hard maple, can be reproduced successfully by seed. They are important saw-timber-producing species, and, as already shown in figure 3, when grown to saw-timber size the diameters attained at given ages by seedlings and seedling sprouts compare favorably with those of sprouts.

White oak type

The original working plan (see under "Reproduction cutting," page 40) provided for the perpetuation of the white oak type as a reserve sprout forest in which white oak, white ash, and white pine of seedling origin should be grown on a long rotation for saw timber, and the other species — chiefly black oak, red oak, and hickory — should be managed in an understory on a short rotation as a sprout forest. This system of management could be employed. However, the establishment, during the twenty-years period, of seedlings and seedling sprouts of all of the more valuable timber-producing species in sufficient number in the aggregate to form fully stocked stands, indicates the feasibility of applying to the white oak type a system of management which is dependent wholly on seedling and seedling-sprout reproduction. The results of reproduction cuttings and of many of the improvement cuttings in older stands suggest the applicability of the shelterwood system. Such a system would result in the perpetuation of even-aged stands without any risk of deterioration. The exact procedure must be worked out by further experimentation. The results of previous cuttings indicate that a two-cut system would be applicable. The first cutting, made when a stand approached maturity, would open up the crown canopy, admitting increased light to the forest floor and possibly stimulating seed production of the dominant trees. The establishment of young growth would result. After such young growth had become established and before it showed signs of suppression the remainder of the mature stand would be removed in a single cutting. The 1905 cutting on plot 7 is an example of a reproduction cutting in a sixty- to sixty-five-years-old stand of the white oak type (Plate VI). This cutting removed trees in all crown classes, especially the less desirable

[10] In their study of advance growth in Connecticut, Leffelman and Hawley (1925) found, for chestnut oak, black oak, red oak, and hickory on three site classes, that of the total young reproduction and advance growth on cut-over land very small percentages only were of sprout origin. In their study a diameter of two inches at the ground line was used as the lower limit of sprout size.

dominant trees and the understory of which hemlock was the principal component. During the twenty-years period young growth of seedling origin sufficient to form a new crop has become established.

Chestnut oak type

For the chestnut oak type the working plan (Peters, 1905) specified the sprout system of reproduction, whereby the forest is managed on a short rotation for cordwood products and allowed to sprout. At maturity it is cut clean. This system was recommended because (1) the two most important species, chestnut oak and red oak, were shown to retain their power to sprout after they had reached relatively large size, (2) chestnut oak is fairly intolerant of shade, especially on the poorer situations, and would not thrive under the composite system of management recommended in the working plan for the white oak type, and (3) it was considered that the coppice system would produce the greatest yield of the product desired in the shortest time (see under "Reproduction cutting," page 40). It has been shown, in the discussion of "Volume growth of sample plots," that the chestnut oak type is too valuable in saw-timber production to be devoted solely to cordwood production on a short rotation. The excellent character of the saw timber present in many of the chestnut-oak stands nearing maturity in 1925, and the abundant seedling and seedling-sprout reproduction of the most valuable species in this type, emphasize the desirability of perpetuating these stands as even-aged high forest rather than as coppice.

From the topography (page 40) it is evident that there is a wide range in quality of site within the chestnut oak type. A typical stand of the better quality is shown in figure 7 (a part of compartment 6 near plot 27). As may be seen in the photograph, this area, tho not well stocked, has produced saw timber of high quality. The improvement cutting, which removed trees in the lower crown classes, has resulted in seedling reproduction of the best species. The 1925 board-foot volumes of plots 31, 32, 36, and 39 (table 6, page 19) suggest the saw-timber-producing ability of the chestnut oak type as found in the better situations. Here a shelterwood system of management similar to that suggested for the white-oak type seems to be applicable.

A summary of the 1905 and 1925 tally sheets for plot 32 is presented in table 2 (page 9). The stand in which this plot is located was heavily cut just prior to the establishment of the plot in 1905. This operation served as a heavy reproduction cutting in which the lower crown classes were greatly reduced, leaving the best dominant trees. As shown in table 2, there was in 1905 no reproduction of 0.6 inch or more diameter breast-high. In 1925 there were 1176 trees per acre in the one-, two-, and three-inch diameter classes. These formed a complete cover of advance-growth reproduction established by the shelterwood system under a mature stand of 8306 board feet per acre (table 6). As shown in table 2, more than 50 per cent of this total reproduction was of the most desirable species — chestnut oak, red oak, and white ash. Red oak, the faster-growing species, might be favored in cleanings, thinnings, and improvement cuttings.

An average acre of the chestnut oak type obtained by combining the tallies of plots 37 and 38 is shown in table 18. Here an even-aged seed-

TABLE 18. AVERAGE STAND PER ACRE ON COMPARTMENT 1, 1905 AND 1925*

Diameter breast-high (inches)	Chestnut oak		Hickory		Red oak		Hard maple		White ash		White oak		Hemlock		Other species		Total	
	1905	1925	1905	1925	1905	1925	1905	1925	1905	1925	1905	1925	1905	1925	1905	1925	1905	1925
1	...	241	22	244	1	105	...	87	3	76	...	25	...	6	1	67	27	851
2	...	73	3	98	...	33	1	41	5	13	...	6	...	...	...	17	9	281
3	1	16	3	25	1	24	1	16	4	3	...	10	...	...	3	16	13	110
4	3	...	2	7	...	11	1	11	2	...	...	...	...	...	7	7	15	36
5	5	...	1	4	...	4	...	2	...	...	...	...	1	...	5	4	12	14
6	...	1	...	2	...	3	...	...	...	...	...	...	...	...	5	2	5	8
7	...	...	...	1	...	...	...	...	...	6	...	...	3	...	2	...	5	7
8	1	...	2	1	...	...	1	...	...	3	...	...	...	...	...	...	4	4
9	1	3	3	...	...	...	...	1	...	...	...	...	1	...	...	...	5	4
10	...	1	4	1	...	...	...	...	...	...	...	...	1	...	...	2	5	4
11	1	...	5	1	...	...	...	1	...	...	...	...	...	2	2	2	8	6
12	...	1	1	...	1	...	1	1	...	...	...	...	1	...	...	1	4	3
13	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	1	0
14	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	0	1
15	...	...	...	...	...	...	1	...	...	...	...	...	1	...	...	1	2	1
20	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	0	1
Total	12	336	46	384	3	180	7	160	14	101	...	41	8	10	25	119	115	1,331

* Derived by combining the tallies of plots 37 and 38.

ling-sprout and sprout stand has become established. On these plots there were in 1905 only 49 trees in the one-, two-, and three-inch diameter classes. After twenty years there were 1242 trees in these diameter classes, of which 80 per cent were oak, hickory, or ash.

Plots 34 and 35 are typical of the poorer sites within the chestnut oak type. On these plots there are frequent bare rock outcroppings which in some instances extend to a vertical height of fourteen feet. The stand shown in figure 2 is typical of such situations. On these sites reproduction is much less abundant than on those discussed above. The reproduction is, however, almost wholly hard maple, white ash, and red oak, of seedling origin. Careful study is necessary to determine the proper silviculture for these sites; the coppice system would seem to be least adapted to their upbuilding. They can never be highly productive.

Hardwood swamp type

As has been stated, drainage ditches were extended into the swamp areas, and thus conditions have been changed since the trees nearing maturity in 1925 became established. In the discussion under "Seedling reproduction" (page 41), white ash is shown to be the most important species of the hardwood swamp type. Of the reproduction on the hardwood-swamp plots, 55 per cent is white ash and 35 per cent is red maple, leaving only 10 per cent for all other species. The white ash is of seedling origin, while the red maple is practically all of sprout origin. The character of future stands on the hardwood swamp type cannot be predicted because sufficient time has not elapsed for adjustments to the changed conditions resulting from drainage. It seems probable that the areas on which white-ash reproduction is abundant may be maintained as high forest, and that the very swampy areas can most profitably be devoted to red-maple coppice for cordwood, clear-cutting the stand when the best trees reach ten to twelve inches in diameter.

On plot 25 reproduction is practically excluded by a complete, dense cover of spice bush.

RECOVERY FROM GRAZING

Compartment 1, in which sample plots 37 and 38 are located, had been grazed heavily prior to 1905. The working plan (Peters, 1905) provided for its management as follows:

> Compartment 1 is an old sheep pasture covered with an open and irregular stand that can be made vastly more productive by planting.....it is believed that red oak is the most suitable tree to plant.....Red oak next to chestnut is the most rapid grower on the tract, and can be planted much more successfully than chestnut.....The best results will be obtained by planting in seed spots on the planting site.

The specific recommendations for management were:

> Cut clean in winter of 1906 and plant red oak in seed spots in spring of 1907. On account of the unsightliness if cut clean, it will be better to extend the cutting over a period of years, taking out about half of the stand in 1906, and the rest in 1912, which will give the young trees ample time to reach a fair size.

A penciled note in the plan indicates that no cutting was done on this compartment in 1906, and there is no record of any planting on this compartment. In 1905 there were many seedlings which sheep had browsed

but which should produce vigorous seedling-sprout growth if protected. The changes which have taken place in this compartment in a twenty-years period are shown in table 18 (page 45). This table is a composite of sample plots 37 and 38. Each of these plots is one-half acre, so that by adding them together an average stand per acre was obtained.

It is evident that a number of the large trees have been cut during the twenty-years period. Protection from grazing has resulted in the establishment of a complete young stand of even-aged seedling, seedling-sprout, and sprout reproduction.

SUMMARY OF CONCLUSIONS

The following conclusions are applicable to the forest studied or to the same types on similar sites.

Diameter growth

1. There is a marked difference in the general trend of diameter-growth curves of sprouts and seedlings.

2. For red oak, white oak, and chestnut oak, there is little choice between sprouts and seedlings, so far as the rate of diameter growth is concerned, if the diameters of trees cut are to exceed ten inches.

3. Thru intermediate and reproduction cuttings the period required to attain merchantable diameters of twelve inches and more for red oak, white oak, and chestnut oak may be reduced from thirty to fifty years.

Volume growth

1. In fully stocked, even-aged stands of the white oak type, periodic annual increment in cubic feet culminates between the thirtieth and the thirty-fifth year, at which time it is about 85 cubic feet per acre per year. The periodic annual increment in board feet culminates at about the seventy-fifth year, at which time it is about 267 board feet per acre per year. (In forests under continuous silvicultural management these increments will be exceeded.)

2. In fully stocked, even-aged stands of the white oak type, the average mean annual increment in cubic feet for stands of merchantable age is 55 cubic feet per acre per year. The average mean annual increment in board feet for stands of merchantable age is 190 to 200 board feet per acre per year. (In forests under continuous silvicultural management these increments will be exceeded.)

3. In the chestnut oak type, increments are less than in the white oak type. Within the type, differences in site quality and in the relative abundance of red oak, the fastest-growing saw-timber species, cause a wide variation in increment.

Silvical effects of cuttings

1. In the white oak type, improvement cuttings in middle-aged stands frequently function as thinnings, for they result in an increase in growth rate of the trees left.

2. In the white oak type, improvement cuttings in stands nearing maturity frequently function as shelterwood reproduction cuttings, for they result in abundant natural reproduction.

3. White pine reproduces abundantly under an open stand of the white oak type if little competition is offered by other woody undergrowth.

4. The important saw-timber species of the white oak type and the chestnut oak type (white oak, chestnut oak, red oak, black oak, hard maple, white ash, hickory, and white pine) can be reproduced successfully by seed.

5. Stands of the white oak type can be reproduced as even-aged high forest. (The shelterwood method may be the best silvicultural system to employ.)

6. On the better sites, stands of the chestnut oak type produce large yields of high-quality saw timber. Therefore they should be reproduced by seed and grown to saw-timber size. The poorer sites are dry and exposed. Reproduction, tho not abundant, is almost wholly of seedling origin. The coppice system is least adapted to their upbuilding.

7. White ash is the most abundant species in the reproduction on the hardwood swamp type. The better-drained areas of the type can be converted into high forest with white ash predominating. The poorly drained areas can most profitably be devoted to red-maple coppice for cordwood.

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BOTANICAL NAMES OF SPECIES MENTIONED

(Botanical names are as given in *Gray's New Manual of Botany*, seventh edition)

Basswood	*Tilia americana* L.
Beech	*Fagus grandifolia* Ehrh.
Bitter-nut hickory	*Carya cordiformis* (Wang.) K. Koch
Black ash	*Fraxinus nigra* Marsh.
Black birch	*Betula lenta* L.
Black cherry	*Prunus serotina* Ehrh.
Black locust	*Robinia Pseudo-Acacia* L.
Black oak	*Quercus velutina* Lam.
Blue beech	*Carpinus caroliniana* Walt.
Butternut	*Juglans cinerea* L.
Chestnut	*Castanea dentata* (Marsh.) Borkh.
Chestnut oak	*Quercus Prinus* L.
Elm	*Ulmus americana* L.
Flowering dogwood	*Cornus florida* L.
Gray birch	*Betula populifolia* Marsh.
Hemlock	*Tsuga canadensis* (L.) Carr.
Hop hornbeam	*Ostrya virginiana* (Mill.) K. Koch
Large-toothed aspen	*Populus grandidentata* Michx.
Pignut hickory	*Carya glabra* (Mill.) Spach
Red cedar	*Juniperus virginiana* L.
Red maple	*Acer rubrum* L.
Red oak	*Quercus rubra* L.
Sassafras	*Sassafras variifolium* (Salisb.) Ktze.
Scarlet oak	*Quercus coccinea* Muench.
Shag-bark hickory	*Carya ovata* (Mill.) K. Koch
Spice bush	*Benzoin aestivale* (L.) Nees
Sugar maple	*Acer saccharum* Marsh.
Swamp white oak	*Quercus bicolor* Willd.
Sycamore	*Platanus occidentalis* L.
Tulip tree	*Liriodendron Tulipifera* L.
White ash	*Fraxinus americana* L.
White mulberry	*Morus alba* L.
White oak	*Quercus alba* L.
White pine	*Pinus Strobus* L.
Yellow birch	*Betula lutea* Michx. f.